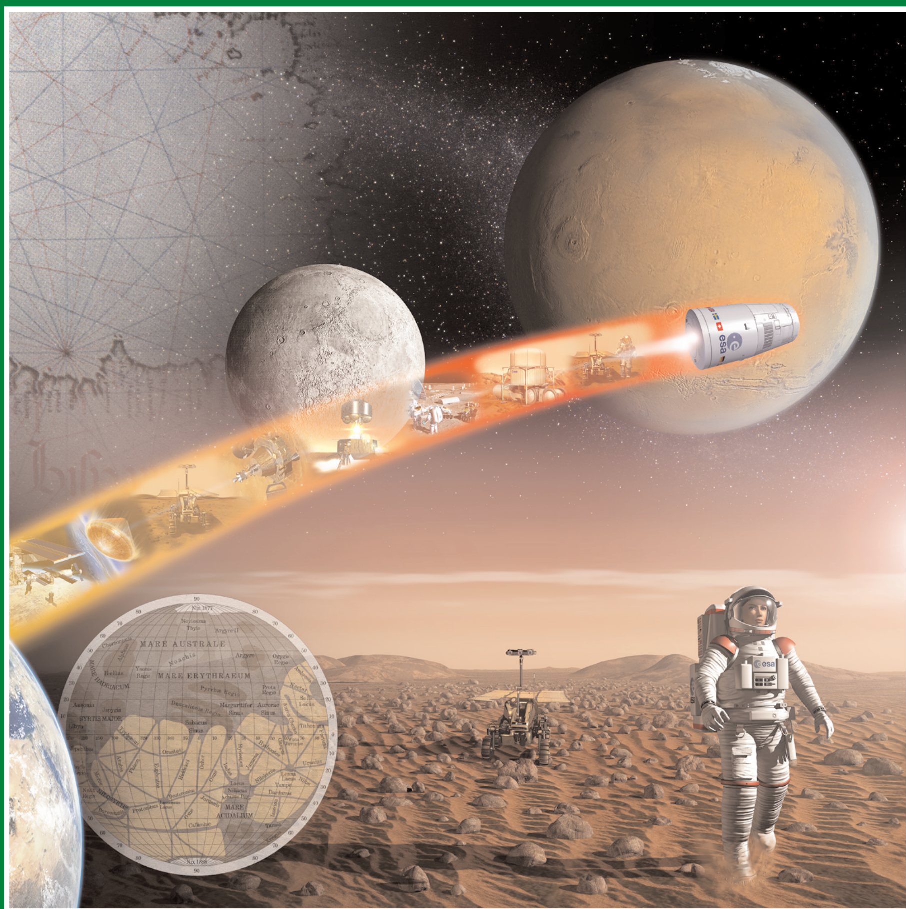
WPP-276

*Joint ESA/NASA Workshop on*

# Planetary Protection & Human System Research and Technology



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ESA/ESTEC, Noordwijk, The Netherlands

European Space Agency
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ESA WPP-276

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# PLANETARY PROTECTION
# &
# HUMAN SYSTEM RESEARCH AND TECHNOLOGY

Held May 19-20, 2005
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*Edited by:*

***Gerhard Kminek***
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## Preface

This report is the third in a series of dedicated workshops on the implications of planetary protection requirements on a human mission to Mars. The deliberations in this workshop took advantage of previous discussions, studies, findings and recommendations related to Mars human missions -- notably those reported in the Pingree Park workshop on "Planetary Protection Issues in the Human Exploration of Mars" in 2001, and the Houston workshop on "Life Support and Habitation and Planetary Protection" in 2005.

Although a human mission to Mars is not foreseen in the near future, the implications of planetary protection requirements on system development and operations in combination with the long lead-time for the development of human-rated systems makes this exercise very timely. A detailed understanding of these aspects is also necessary in order to discuss the unavoidable consequences of humans on Mars in the framework of the planetary protection policy at COSPAR level.

This report presents information on the discussions and opinions of workshop participants; as such, it does not necessarily reflect official agency positions.

Gerhard Kminek
Planetary Protection Officer, ESA

John D. Rummel
NASA Planetary Protection Officer
(Now NASA Senior Scientist for Astrobiology)

December 2007

## Acknowledgements

The workshop organizers (G. Kminek and J.D. Rummel) would like to acknowledge the efforts of all participants in the workshop. Their collective expertise and insight during workshop deliberations contributed to the overall workshop recommendations and this report. The organizers would also like to thank M. Race for preparing this workshop report.

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## Executive Summary

Planetary protection requirements for future human missions to Mars will strongly influence mission and spacecraft designs, particularly those related to the operation of advanced life support systems (ALS), extravehicular activity (EVA), laboratory and *in situ* sampling operations, and associated environmental monitoring and control systems. In order to initiate communication, understanding and working relations among the ALS, EVA, and planetary protection communities in NASA and ESA, a workshop was held (May 2005; ESA/ESTEC; Noordwijk, The Netherlands) to focus on mission-specific planetary protection issues associated with future human missions to Mars. The "Mars Planetary Protection and Human Systems Research and Technology Joint ESA/NASA Workshop" considered the range of knowledge and information necessary to establish planetary protection implementation guidelines with respect to ALS and EVA systems, including the identification of potential contaminants, contamination pathways, and potential off-nominal events typical of such systems and of space exploration. The top-level workshop goal was to determine how planetary protection requirements should be implemented before, during, and after human Mars missions, and what standards of contamination control should apply to human explorers.

The workshop began with a number of plenary presentations that covered the findings and recommendations of previous relevant workshops, notably the Pingree Park workshop of 2001 (Criswell *et al.*, 2005) and the Houston workshop of April 2005 (Hogan *et al.*, 2006). These presentations were followed by splinter group discussions organized around three main areas, each with implications for planetary protection on human rated systems:

Advanced Life Support Systems (ALS)
Extravehicular Activities (EVA) and
Operations and Support (OPS)

Splinter group discussions considered operations and technology concerns, science activities and operations, backward contamination prevention requirements, and the protection of both the human habitat on Mars and the Earth upon crew return. They also identified future research and development needs for ALS, EVA and Mars robotic missions, including specific precursor mission information necessary to understand and prepare for human support systems and science operations on long duration Mars missions.

The detailed splinter group reports and their respective findings are presented in later sections of this workshop report. The splinter group reports were discussed in plenary sessions and integrated into the overall workshop findings and recommendations. The overall workshop findings and recommendations reflects the findings, recommendations as well as research and development needs identified during the workshop discussions and represent a consensus of all three splinter group chairs.

## Overall Workshop Findings and Recommendations

**Premise:**
Planetary protection goals *per se* should not be modified to accommodate a human mission to Mars, and don't need to be abandoned if humans are to study the planet.

*"Where there are legitimate differences of opinion in discussions of planetary quarantine, the burden of proof must fall on those advocating a relaxation of standards"* (Sagan *et al.*, 1968).

**Consensus Starting Positions:**

- Safeguarding the Earth from potential back contamination is the highest planetary protection priority in Mars exploration.
- The greater capability of human explorers can contribute to the astrobiological exploration of Mars only if human-associated contamination is controlled and understood.
- It will not be possible for all human-associated processes and mission operations to be conducted within entirely closed systems.
- Crewmembers exploring Mars will inevitably be exposed to martian materials.

## General Considerations and Recommendations:

### I. POLICY

1. It does not make sense to have separate planetary protection policies for human and robotic mission. The reasons for protecting Mars and Earth are invariant in this context.

2. Planetary protection requirements imposed 'at launch', as done for robotic missions, are not entirely sufficient for human missions. The biological contamination on a human mission will change over time. Therefore, an evaluation of the biological contamination on the spacecraft will be mandatory throughout the mission because of its potential for both forward and back contamination.

3. Planetary protection requirements for early human missions should be based on a conservative approach consistent with continuing uncertainties about martian life. Planetary protection requirements for later missions should not be relaxed without scientific review, justification, and consensus.

4. There will be a need to develop a comprehensive planetary protection protocol for human missions that encompasses considerations of forward and back contamination for both robotic and human aspects of the mission, and includes associated sample handling and science activities on both Mars and Earth (similar to the comprehensive protocol developed for robotic sample return missions; e.g., Rummel *et al*, 2002).

## II. SPECIAL REGIONS

1. For outbound spacecraft on human missions, pre-launch cleanroom assembly will be required of all systems regardless of planned landing site.

2. For those systems that will land in or be deployed in Special Regions, appropriate quantitative bioburden reduction requirements will apply.

3. Neither robotic systems nor human activities should contaminate ‘Special Regions”, as defined by COSPAR policy.

~~4.~~ Special Regions should be further considered in relation to the potential for *Local* vs. *Global* distribution of biological contamination~~.~~

## III. OPERATIONS AND CREW

1. Any uncharacterized martian site must be evaluated by robotic precursors prior to crew access. Information may be obtained by either precursor robotic missions or a robotic component on a human mission.

2. Any pristine samples or sampling components from any uncharacterized sites or Special Regions on Mars should be treated according to current planetary protection category V, restricted Earth return, with the proper handling and testing protocols.

3. An onboard crewmember should be given primary responsibility for the implementation of planetary protection provisions affecting the crew during the mission.

4. Human Factors (psychological, physiological or other possible impairments) need to be considered along with planetary protection issues for human missions.

5. Crew protection and back contamination requirements may influence *in-situ* resource utilization (ISRU) operations. Of particular concerns will be those activities that create resources or materials that can be transported into the habitat and can be inhaled or consumed by the crew.

6. Robotic precursor missions will be essential for ensuring that plans and designs of human missions to Mars are appropriate to safeguard the crew from potential martian biohazards.

## IV. WASTE MANAGEMENT

1. Any solid or liquid waste produced on Mars should require containment or sterilization prior to disposal.

2. No uncontained liquid or solid waste products should be buried on Mars.

3. Any vented gaseous products should be filtered prior to release (e.g., from spacecraft, habitat, suits, rovers etc.).

4. Prior to leaving the planet, decontamination of the habitat (and equipment left behind) is required &/or stabilization of the bioburden within the habitat.

## V. RESEARCH & DEVELOPMENT

Areas of important science research and technology development identified by the workshop include understanding and evaluating**:**

1. Survival of spacecraft associated terrestrial organisms and their molecular components in the ambient martian environment.

2. Near and far-field contamination transport models.

3. Quantitative & Qualitative life support system process streams (air, water, wastes etc) for human rated systems (e.g., habitat, suits, rovers etc.).

4. The impact of planetary protection requirements on various types of ISRU operations & systems.

In addition, there is the need to develop the following:

5. Real-time monitoring system(s) for potential 'unknown' biology within pressurized volume.

6. Sterilization and decontamination capabilities for generated wastes, spacecraft volumes (e.g., habitat, suits, rovers etc.) and associated equipment and samples.

7. Containment capabilities for generated wastes, spacecraft volumes, associated equipment, samples and crew (quarantine).

## Workshop Description

With both NASA and ESA beginning long-term plans for their respective sequencing of robotic and human missions, it is necessary to consider how planetary protection controls for the eventual human exploration of Mars can be incorporated into missions in ways that ensure the preservation of scientific opportunities as well as human health and safety, both on Mars and upon return to Earth. Planetary protection requirements will strongly influence mission and spacecraft designs, particularly those related to the advanced life support systems (ALS), extravehicular activity (EVA), and operations and support (Ops).

In order to initiate communication, understanding and working relations between the ALS, EVA, and planetary protection communities in NASA and ESA, a special workshop "The Mars Planetary Protection and Human Systems Research and Technology Joint ESA/NASA workshop" was held May 19-20, 2005 at the European Space Research and Technology Centre (ESTEC), Noordwijk, The Netherlands to focus on mission-specific planetary protection issues for future human missions to Mars (see Appendix B for workshop agenda). The workshop, convened jointly by the ESA/Aurora Program, and NASA Planetary Protection Office, was designed as a follow-on to two previous workshops on planetary protection and human mission to Mars, one in Pingree Park, Colorado in June 2001 (Criswell *et al.*, 2005), and the other in Houston, Texas in April 2005 (Hogan *et al.*, 2006).

Each of the earlier workshops provided useful information for future human exploration planning, and helped to understand how to integrate planetary protection considerations with two other important concerns -- the preservation of scientific opportunities, and maintenance of human health and safety. These three considerations, planetary protection, science objectives, and crew health and safety, will undoubtedly affect both precursor robotic mission planning, as well as the design and operation of human support systems and missions. This workshop sought to take discussions to the next level of analysis.

Ultimately, the top-level goals of this workshop were to determine how planetary protection requirements will be implemented during human missions, and what standards of contamination control will apply to human explorers. The **workshop objectives** are:

- To initiate communication, understanding and a working relationship between the ALS, EVA, and planetary protection communities.
- To initiate identification of knowledge necessary to establish planetary protection requirements with respect to ALS and EVA systems, including the identification of potential contaminants, contamination pathways, and potential off-nominal events typical of such systems.
- To explore the needs of exobiology experimentation and how ALS and EVA systems may impact them.
- To explore issues concerning the disruption of an extraterrestrial ecology via ALS or EVA operations.
- To explore the issues of interplanetary waste/water jettisoning.
- To explore the issues of waste/water/gas storage or disposal on or under the martian surface.

- To examine how ALS and EVA systems interact with back-contamination requirements for protection of the human habitat on Mars, and of the Earth.
- To identify future research needs for ALS, EVA, and Mars robotic-missions, and to identify precursor mission requirements to understand and prepare for human support systems on Mars and for use enroute.

The workshop participants included 39 individuals selected for their combined expertise and experiences in areas relevant to advanced life support, extravehicular activity, operations and support, and planetary protection. The heart of the workshop deliberations occurred in break-out or splinter groups which focused on specific assignments relevant to the workshop goals. The original splinter groups assignments for the participants are shown in Appendix C, along with contact information and institutional affiliations for all participants. All participants used the following **consensus starting positions** to guide splinter group and plenary deliberations:

- Safeguarding the Earth from potential backward contamination is the highest planetary protection priority in Mars exploration.

- The greater capabilities of human explorers can contribute to the astrobiological exploration of Mars only if human-associated contamination is controlled and understood.

- It will not be possible for all human-associated processes and mission operations to be conducted within entirely closed systems.

- Crewmembers exploring Mars will inevitably be exposed to martian materials.

The workshop began with a series of tutorial presentations providing general information on planetary protection and detailed findings of two previous planetary protection workshops focused on human missions (Hogan *et al.*, 2006; Criswell *et al.*, 2005). (Appendix D provides information on the speakers and their specific presentations). Subsequently, participants were assigned to one of three independent splinter groups: 1) Extravehicular Activities (EVA), 2) Advanced Life Support (ALS), and 3) Operations and Support (Ops). Each group was asked to discuss and describe how planetary protection requirements could be implemented during human missions to Mars, contrasting initial human missions versus later human missions, if appropriate, and how planetary protection requirements would impact the design of various human support systems.

In addressing their assigned areas, each splinter group was asked to address the following **specific questions:**

1. What is the overall approach to contamination control, including:
   Forward & backward contamination levels in different areas (e.g., zones of contamination control), and
   Quarantine requirements (for crew and samples)?

2. What is the approach to waste & consumables management, focusing on:

Different mission phases (e.g., transit, planetary surface), and
Different types of wastes & consumables, and their levels of contaminants and dispersion properties?

3. What are the off-nominal events that could potentially lead to a contamination of Mars or the terrestrial biosphere?
   Identify the consequences and suggest mitigation strategies.

4. What are the research and development activities required to cope with planetary protection requirements?
   Identify research and development requirements for both human- and associated robotic-precursor missions.

Participants acknowledged that planetary protection requirements should be based on a thorough knowledge of potential contamination pathways and characteristics, and a current understanding of the biological potential of Mars. In addition, it was recognized that the robotic precursor program will search for life on Mars before the introduction of human-associated biological contamination. Moreover, precursor missions will be important in attempts to determine the presence or absence of human-affective biohazards on the martian surface, and to establish sufficient information to determine Zones of Minimal Biologic Risk (ZMBRs) as recommended by the US National Research Council (NRC, 2002).

## Splinter Group Findings and Reports

The sections below present the summary findings for the ALS, EVA and OPS splinter groups, which ultimately contributed to the overall workshop conclusions and recommendations.
In addition of using the consensus starting positions, all splinter groups had an additional list of specific objectives to guide and focus their deliberations (see Appendix E).

### 1. Advanced Life Support Systems Splinter Group

**Co-chairs:** C. Lasseur and M. Kliss
**Participants:**

| | | |
|---|---|---|
| K. Buxbaum | R. Fisackerly | P. Heeg |
| S. Hoffman | R. Lindner | P. Mani |
| J. A. Spry | P. Stabekis | |

***1.1 Overview of Advanced Life Support Subgroup (ALS) Deliberations***

Advanced Life Support (ALS) represents a suite of enabling capabilities necessary to support human exploration missions (e.g., air revitalization, water recovery, thermal control, solid waste management, and advanced food technology and crop systems). As integrated technologies, they provide the necessary transport, exchange, and recovery of gases, liquids, solids and thermal regulation required to maintain human life in the space environment. For future planetary missions, new advanced life support systems are needed to decrease dramatically the dependency on resupply consumables, as well as to decrease the mass, energy and volume of future spacecraft and payloads. Key design aspects of ALS systems include "closing the loop" to recover usable mass; decreasing the requirements for expendables, energy, volume, heat rejection and crew time; utilizing *in situ* resources; and providing a high degree of reliability.

Advanced life support systems for missions to Mars will not be completely closed, however, and accordingly have the potential to contribute to both forward contamination of Mars and backward contamination of Earth. It is reasonable to expect that materials cycling within human-rated habitats will be highly contaminated with microbial life that, if released outside of the habitat, can potentially be a significant source of forward contamination. Conversely, conservative plans would assume that any martian life forms transported into the habitat would have the potential to become established either in humans or in life support system materials and hardware. These organisms may then be transported back to Earth on the return voyage, leading to potential backward contamination.

Planetary protection thus represents an additional set of requirements that may influence ALS system design. For example, current cabin air management systems typically employ external venting to reject unwanted gas streams, including concentrated carbon dioxide, methane, and other contaminants. Planetary protection requirements may require that certain components be removed from these streams or decreased in amount. Waste management systems may also involve venting gaseous products to the martian atmosphere, but will also need to comply with planetary protection requirements that control the extent and character of organic inventory and storage of potential forward contaminants (i.e., wastes).

Likewise, scientific investigations that are designed to search for current or past life on Mars may also influence ALS system design. Science priorities would include elimination of contaminants that would confuse or obscure the science measurements. Of particular interest to scientists will be the control over the release and dissemination of specific materials from humans, foods, wastes and hardware that may be designated as biosignatures or biomarkers.

Since it is anticipated that planetary protection requirements may influence ALS technology selection and system design for future missions, these requirements should be incorporated into technology development programs, including those for the Moon if there is expected to be technology carry-forward into Mars exploration.

As part of their starting deliberations, the subgroup determined it would *not* contrast early vs. later missions in their workshop discussions. They reasoned that planetary protection requirements will not likely become more relaxed in later missions, since a conservative approach will be followed if there is continuing uncertainty about martian life. On the other hand, if extinct or extant life is found in the future, planetary protection requirements may become even stricter, not less so.

In considering the design of human support systems, the subgroup agreed that planetary protection and science-based requirements may influence ALS technology trade options, technology selection, system design, and system development costs. In addition, planetary protection requirements may affect the kind of operations, processes, and functions that can take place during future planetary exploration missions. Forward contamination requirements may limit the discharge of liquids, solids, and gases. Crew protection and backward contamination requirements may influence ISRU operations, particularly those that create resources that are transported into the habitat and can be inhaled or consumed by the crew. Additionally, waste, water and air management systems will need to handle contaminants that enter the habitat through crew ingress/egress, and returning samples or hardware.

The recommended approach is to design ALS systems to limit leakage/contamination to TBD levels, bearing in mind that closed systems are the ideal. Sterilization and decontamination capabilities will be required for generated wastes, spacecraft volumes (habitats and labs), and associated equipment.

### *1.2 ALS Sub-Group Responses to Assigned Questions*

Question 1 - What is the overall approach to contamination control?

The ALS subgroup began discussions by debating whether unmanned missions transporting ISRU or ALS assets to Mars prior to human landing would be considered robotic missions (and accordingly fall under planetary protection requirements for robotic missions) or human missions (and fall under their planetary protection requirements). Since the objectives and payload envelope of these precursor missions are more closely aligned with human missions than robotic science missions, the subgroup suggested a revision in wording for the conceptual approach as follows: "Human missions to Mars, *including associated missions to emplace assets (e.g., ISRU, ALS consumables)* should not affect or otherwise contaminate "special regions" of Mars, as defined in the COSPAR Planetary Protection Policy of October 2002."

There was also considerable discussion about the realities of forward contamination during human missions, in which bioburden will necessarily increase during transit. The subgroup noted that while it may be appropriate to require that "No quantitative bioburden requirements should be applied to landing systems or habitats, other than clean room assembly," it will be necessary to impose additional controls to address in-transit contamination issues such as:

– the generation of additional (post launch) human-associated contamination including solids and liquids in general and microbes in particular, and
– the transfer of this contamination and its effect on the current and subsequent mission objectives.

Discussions also focused on quarantine requirements for the entire crew vs. quarantine for an individual crewmember. If there is a requirement for *individual* quarantine, then a *separate* ALS will be needed within the facility to test and/or evaluate individual crewmembers. No unique ALS capability is required for the quarantine of the *entire* crew. In either case, the Earth entry segment of the mission would require a leak-proof ALS in order to break the chain of contact with Mars as much as possible.

Question 2 - What is the approach to waste & consumable management for different mission phases?

Waste and consumable management strategies were considered for both the transit portion and the surface mission phases. From a planetary protection perspective, the best approach for managing wastes generated during the transit portion would be to ensure that they are not brought to the surface. During Mars transit, water would be recovered from wastes to stabilize them, and the dry solids would be contained. Ideally, these contained wastes would then be actively jettisoned (with a kick motor or other propulsive device) such that they would not enter the martian atmosphere. All active jettisoning would be done in such a way that the outside surfaces of the spacecraft were not contaminated. Any wastes that were brought to the martian surface would require containment and/or sterilization.

For planetary surface mission operations, both short stay (30-60 days) and long stay (300 day) scenarios were considered. The waste management approach was the same for both durations. All wastes would be contained for a TBD period and/or sterilized, and left on the surface. It was recommended that wastes should not be buried. Prior to leaving the planet, decontamination of the habitat or stabilization of the bioburden within the habitat would be required.

Although it was recognized that various types of wastes and consumables have different bioburden and contamination potentials, there was insufficient time at the workshop to address this issue fully. The initial recommendation was to use an overkill approach and make no differentiation between waste and consumable types and assume a high burden on everything.

Question 3 - What are the off-nominal events that could potentially lead to contamination of Mars or the terrestrial biosphere? (Also: Identify consequences and suggest mitigation strategies)

There are many off-nominal events related to ALS systems that could potentially lead to contamination of Mars or the terrestrial biosphere (e.g., off-nominal leakage from the habitat, airlocks or other vessels; malfunction of the airlock/transferlock/dustlock; contingency venting during off-nominal over pressurization; premature failure of waste containers or waste management systems; ISRU resource generation and use; and unintentional discharges from life support equipment). In virtually all cases the root cause of contamination would be either a breach of containment, the failure of sterilization/decontamination systems, or exposure to the martian environment. Mitigation strategies include identification of best design practices for reducing risk, and development of operations and procedures for contingency/off-nominal response.

Question 4 - What is the R&D required to cope with planetary protection requirements?

### *1.3 ALS Research and Development Needs*

The ALS subgroup identified a list of topics needing future R&D attention, including:

1. On-line, real time genetic identification of biological organisms in ALS.

2. Near field and far field models for contamination transport to guide adequacy of planetary protection requirements for human missions.

3. Quantitative and qualitative knowledge of ALS system process streams (air, water, waste, etc.) to assist in assessing potential forward contamination risks, and in developing

mitigation approaches.

4. Prediction or measurement of how the martian environment (e.g., radiation, temperature, chemistry) would contribute to passive mitigation of forward contaminants.

5. Characterization of contaminant releases from the cabin via leakage, intentional venting and general mission operations.

6. Identification of pertinent air, water and waste management technologies for processing, containment, and disposal that comply with anticipated planetary protection and science-based constraints (for surface and interplanetary space).

7. System analyses to determine the viability of the surface waste storage concept for various waste processing scenarios.

8. Re-examine and modify ALS reference mission designs as necessary to harmonize with planetary protection and science-based requirements.

* * * * *

The individual ALS splinter group report was subsequently presented and discussed in a plenary session (see Appendix H for splinter group presentations) along with reports from other splinter groups. The plenary discussions led ultimately to set of integrated workshop conclusions and recommendations, and a list of combined R&D issues that need attention (see overall workshop findings and recommendations).

## 2. Extravehicular Activity Splinter Group

**Chair**: J. Kosmo
**Participants:**

| | | |
|---|---|---|
| D. Anderson | D. Beaty | A. Debus |
| S. Hovland | G. Kminek | C. McKay |

### *2.1 Overview of EVA Subgroup Deliberations*

The EVA Splinter Group decided to emphasize Question #1 (approach to contamination control) because of its importance for addressing all other questions. In doing so, their discussions also reconsidered the assumptions and basic concepts underlying planetary protection, and discussed how they might evolve in the future to facilitate technically achievable and effective scientific exploration, planetary protection, and support during human missions.

In considering the overall approach to contamination control, the EVA subgroup first addressed specific issues associated with forward contamination. In particular, they focused on the science goals associated with future missions (as outlined in MEPAG, 2004)[1] and acknowledged that one

[1] MEPAG: Mars Exploration Program Analysis Group, a science planning group that provides input to NASA.

of the primary purposes of planetary protection policy is to enable future scientists to make and confirm a life-related discovery. This necessarily involves the avoidance of false positives and an understanding of Earth-sourced organic contamination, whether living and non-living. It also requires a focus on both local and global contamination perspectives.

### *2.2 EVA and Forward Contamination Considerations*

Two kinds of spacecraft contaminants have the potential to interfere with investigations of possible martian life: live organisms and non-living organic material, both of which are impossible to remove from spacecraft prior to launch. Live organisms can be transformed to dead ones by sterilization (e.g., heating), but they often cannot be quantitatively removed. Thus, an important challenge will be distinguishing evidence of organic material or life on Mars ("signal") from organic material or life we bring with us ("noise"), recognizing that it will not be possible to eliminate the noise altogether. Since each type of life-related contaminant has a different potential to interfere with science measurements, effective contamination control strategies are essential parts of the logic for future missions designs and science investigations.

The organic contaminants on landed spacecraft (whether living or non-living) *will* contaminate the site of the landed operations, necessitating the continued use of methodologies to acquire clean, sterile, samples from a platform that is 'dirty', and transfer these samples to clean, sterile instruments. A much greater threat lies in the fact that live organisms, because of their potential to reproduce, have the potential to multiply and spread and amplify the signal, even from a small initial contamination event. For this reason, the subgroup concluded that Forward planetary protection strategies must include a distinction between 'local' and 'global' contamination events.

#### *2.2.1 Global vs. Local Contamination Considerations*

The EVA subgroup asserted that protecting Mars will require that the concepts of global vs. local contamination be incorporated into forward planetary protection policy. They suggested that this can be accomplished by modifying the current COSPAR definition of "special regions" to distinguish areas within which contamination would have local effects only, vs. those within which contamination could propagate to other environments, potentially on the planetary scale. For discussion purposes they were referred to as *regions of local contamination risk*, and *regions of global contamination risk*. Although it is not possible at this time to provide scientific details associated with the two different categories, establishing this dual policy option will encourage the collection of relevant information for future missions.

Considering a three-dimensional perspective, already it is known that certain regions on Mars are likely to have higher potential for extant indigenous life (and also for the support of introduced Earth microbes) due to important parameters such as temperature, inferred presence of water, and protection from ionizing radiation. All of the potential places identified to date occur either as broad regions (e.g., the region of the polar ice cap), or as large populations of specific features (e.g., gully systems). It will be important to investigate such places, even though doing so also will introduce a potential for microbial contamination of the site. Nonetheless, if such contamination is of local impact only, it is a very different matter than if the contamination has the potential to amplify and expand to either regional or global extent. The degree of uniqueness of the site to be visited must also be considered in assessing whether or not contamination should be allowed.

*2.2.2 Proposed Three-Zone System and Implementation Implications*

Building on the existing defined special regions (COSPAR 2002), the EVA subgroup proposed the idea of amplifying the categorization into three zones.

> Proposed Zone 1. **Non-special region.** The inverse of a special region. A site for which *growth or propagation of Earth organisms is unlikely, and which has low potential for the existence of extant martian life.* By definition, this kind of region *is not* of interest for extant life detection investigations (but may be of interest for extinct life investigations).
>
> Proposed Zone 2. **Region of local contamination risk**. A region where terrestrial organisms are likely to propagate or where there is high potential for the existence of extant martian life, *but where biological contamination can reasonably be expected to have local effects only* (global propagation, within TBD time scale, is considered to be of low probability). By definition, this kind of region *is* of interest for extant life detection.
>
> Proposed Zone 3. **Region of global contamination risk.** A region where terrestrial organisms are likely to propagate or where there is high potential for the existence of extant martian life**,** but *where biological contamination has the potential to spread in a global sense*. By definition, this kind of region *is* of interest for life detection.

The EVA sub-group also discussed the varied implementation implications of their three-zone scheme, noting that regions of global contamination risk need a much higher level of protection than regions of local contamination risk. As an example, if an acceptable case can be made that a mission's activities would contaminate only the immediate area, and that the biologic contamination could not spread either to a much larger volume of ground ice, or to a possible underlying aquifer, one could argue that the consequences of site contamination are acceptable. In contrast, if contamination of the site would likely spread beyond the local site, the consequences would be unacceptable, and preventive restrictions would need to be applied.

There should also be a way to consider the uniqueness of martian features or areas if a mission is proposed for local contamination as per Zone 2 above. It is important to protect unique or rare martian geologic phenomena, either currently known or yet to be discovered. For example, if a geyser were discovered on Mars, it should be explored with extreme care, even if a case could be made that contamination would have local effect only. Thus, in addition to considering local vs. global, there needs to be provisions to protect rare occurrences.

The subgroup also discussed the implications of their new zoning categorization in relation to current COSPAR standards and bioburden levels and offered thoughts about the issues and possible evolution of policy using their proposed three zone categorization. As part of their deliberations, the future Phoenix mission was examined as an exercise to focus on the implications of a revised zonation scheme. Information on this hypothetical exercise is provided in Appendix F.

They also noted that an important implementation consideration will be to ensure that specified cleanliness levels are below the detection thresholds of the instruments used in searching for organic compounds, to avoid false positives from detecting terrestrial contamination. In the past, this has been hard to implement in a practical sense—sensor technology is such that it hard to avoid measuring the background. In any case, there clearly is value in working on cleanliness technologies, control and on how to maintain the cleanliness chain.

### *2.2.3 Relationship to Human Missions*

To date there is no general agreement on the scientific objectives that would be assigned to the first and/or subsequent human missions to Mars. If one of the objectives of the first human mission were to carry out extant life investigations, the mission would need deliberately to seek out places that have high biological potential, which in turn could lead to unacceptably high planetary protection risks. Reduction of that risk involves sending precursor missions to determine whether or not biological hazards are present at the landing site (Beaty *et al.*, 2005). Sending human missions to places with negative precursor findings may seem counterproductive scientifically. However, sending humans to a place with positive precursor results may result in exceeding acceptable risk thresholds for forward and/or backward contamination. One way to resolve this paradox may be if the human mission is designed to investigate extinct martian life (which would not have a backward contamination risk).

## ***2.3 EVA and Backward Contamination Considerations***

Maintaining a livable and healthy environment in Mars surface habitat will be imperative. However, numerous planetary protection concerns and backward contamination pathways will arise during normal EVA surface operations. The subgroup identified the many types of pathways and operations that will take place on a daily to weekly basis during a human mission, including:

- Airlock operations: Transport of dust & regolith materials from surface into airlock and subsequently into habitat living areas.
- Crew contamination during don of spacesuits; inhalation / ingestion during EVA; inseparable transfer into habitat & to Earth.

Return from remote EVA worksites & surface traverses:

- Transport of "non-documented/classified " surface materials back into airlock/habitat living areas.

Geologic/astrobiological sample collection activities (surface & sub-surface ops):

- All of the above concerns associated with human-assisted operations.
- Handling of samples (in-situ) or in habitat laboratory for analysis.

Transfer EVA prep / servicing / maintenance items into habitat:

- Surface contaminants and contaminants in cavities, seal regions, porous materials, between layers, etc.
- Limitations of practicable cleaning processes prior to airlock entry / in airlock.

ISRU Operations Phase:

- All of the above concerns; perhaps magnified based on the extent of operations.

### *2.3.1 Back Contamination Implementations*

In considering the backward contamination implications of the return mission, the following thoughts were suggested for avoiding the transport of hazardous materials to Earth's biosphere:

> <u>Implementation Option 1</u>. All martian material contained or sterilized. Breaking the chain of contact is achievable by robotic missions, but this is not practical for nominal human missions.
>
> <u>Implementation Option 2</u>. If prior missions have established site is not hazardous (but not necessarily dead), breaking the chain of contact will not be required. This will apply to both robotic missions and early human missions feeding forward to later human missions.
>
> > <u>Contingency Capability Required</u>: Empower the astronauts to respond to possible unexpected indications of extant life and/or possible exposure. The mission will need the tools and training to assess and control possible martian biology if encountered, such as:
> > – On-board capability to detect and understand hazard;
> > – Sterilization capability (method should be effective);
> > – Personnel isolation capability.
> >
> > <u>Emergency procedure if a hazard is discovered</u>: We need to have a plan for returning astronauts to Earth, even if they have been contaminated by martian life.
> > – Need emergency crew transfer capability to quarantine facility on Earth.

For backward contamination, there is an interesting trade-off between science and planetary protection. Minimizing the risk of contamination for astronauts (and consequently bringing the biohazard to Earth) would suggest landing and staying in Zone 1. However, collecting samples for exobiological examination would suggest a need to access Zone 2 or Zone 3 where the probability of contamination is the highest.

## ***2.4 EVA Planning and Suit Engineering***

The EVA community needs realistic requirements for EVA planetary protection that

a) are tolerant of EVA hardware systems design feasibility limitations,
b) have technical practicality,
c) have tolerable impact to mission planning and operations,

d) have an architecture so as not to significantly affect human functional performance capabilities, and
e) are acceptable to both the planetary protection and science communities.

Because planetary protection requirements will be costly, a reasonable way to mitigate these costs is to identify these requirements early in the development cycle.

Although the EVA community knows what gases vent from current suit designs, it does not know what levels of these constituents are acceptable from a forward contamination standpoint. In addition, the EVA community does not know what level of biological and organic material is contained within these gas releases from any EVA suit during the course of normal operations. Thus, human space suit chamber tests using sample tracer elements or markers will be important to determine biological and chemical signature characterizations generated by space suit system venting and leakage effluents.

***2.5 Prototype Future Planetary Protection Requirements for EVA***

Based on their deliberations, the EVA subgroup developed an extensive list of possible planetary protection requirements for further consideration and discussion. These requirements focused on bioburden requirements for future missions to both 'special' and non-special regions; linkage of cleanliness levels and contamination allowances with scientific objectives; consideration of both local and global contamination risks for setting categorical designations and cleanliness levels; filtering of all vented gaseous materials from spacecraft, landers, habitats and rovers; contained disposal of all solid and liquid wastes; isolation of human explorers from direct contact with martian materials; and provision for appropriate quarantine capability for both the entire crew and individual astronauts in the event of uncontrolled contacts and exposures with martian materials. Like requirements for robotic missions, all samples collected from uncontrolled or untested areas of Mars should be considered potentially hazardous, and subjected to a series of rigorous tests and/or sterilization before release from containment. In concluding, the subgroup identified several topics needing further discussion including bio-burden verification procedures, organic cleanliness protocols and definition of what constitutes "regional" or "global" impacts.

* * * * *

The individual EVA splinter group report was subsequently presented and discussed in a plenary session (see H for splinter group presentations) along with reports from other splinter groups. The plenary discussions led ultimately to set of integrated workshop conclusions and recommendations, and a list of combined R&D issues that need attention (see overall workshop findings and recommendations).

## 3. Operations and Support (OPS) Splinter Group

**Chair:** B. Ward
**Participants:**

| | | |
|---|---|---|
| B. Clark | J.F. Clervoy | D. Eppler |
| G. Horneck | J.P.Pereira | M. Race |
| F. Raulin | J.L. Vago | |

The Ops subgroup used the basic workshop assumptions, conceptual approach and a focus on 'special regions' as they deliberated about the assigned questions. Their findings about forward and backward contamination and their suggestions on R&D topics are summarized below.

### *3.1 Operations and Support (OPS) Forward Contamination Considerations*

- Human mission planning, including landing site selection, base location, and mission objectives, should follow from precursor robotic information and evaluations made at those sites and/or from information developed from a sample return mission or missions.
- Definition is needed for a system describing and categorizing martian sites of special scientific interest (special regions) and their level of contamination concern. The classification system should be developed and employed in future planetary protection protocols, as well as in operational plans for later human missions to Mars.
- Additional development and design attention is needed to characterize exploration, sampling, and base activities both to assure effective operation and provide the required level of planetary protection assurance:
  – The processes associated with EVA egress/ingress must be characterized and optimized.
  – An inventory of microbial populations carried aboard and potentially released by human-associated spacecraft and suits should be established and maintained in support of both planetary protection and crew-health objectives.
  – An inventory of organic materials carried by, or potentially produced by, the mission should be established and maintained.
  – Systems should be provided to allow controlled, aseptic, subsurface sampling operations to avoid terrestrial or human associated contamination of the subsurface samples.
- Quantitative requirements to limit human-associated contamination in different zones should be derived based on requirements for protection of special regions and applied to missions, with the following stipulations:
  – No quantitative bioburden requirements should be applied to landing systems or habitats at launch, other than clean room at least ISO 8 (Class 100K Cleanroom) assembly of Mars-contacting components.
  – Spacecraft, landers, habitats, and rovers should all (to the maximum possible extent) filter material vented as gases, and should not allow uncontained disposal of solids or fluids.
  – Hardware elements involved with accessing special regions should be subjected to a sterilizing process prior to use.

### *3.2 OPS and Backward Contamination Considerations*

- All operations of a human mission to a new site on Mars should include isolation of humans from directly contacting martian materials until initial testing (either precursor-mission or on-mission robotic testing) can provide a state-of-the-art verification of the landing site as a "zone of minimum biological risk" (provide for the informed consent of the crew).

- Exploration, sampling, and base activities should be accomplished in a manner to limit inadvertent exposure to the subsurface or to otherwise-untested areas of Mars. A means for allowing controlled access to those areas should be provided.
- A site classification system and a biological plausibility map of the martian surface and subsurface, based on remote sensing data and on-mission testing, should be employed during a mission to limit potential crew exposure to areas on Mars that might support martian life.
- A quarantine capability for both the entire crew and for individual crewmembers should be provided during and after the mission, in case potential contact with a martian life-form occurs:
  - As part of normal crew health monitoring and in support of the assessment of possible quarantine measures, basic tests of the medical condition of the crew and their potential response to pathogens or adventitious microbes should be defined, provided, and employed regularly on the mission.
  - A quarantine capability and appropriate medical testing should be provided for the crew upon return to the Earth (or Moon or Earth-orbit)[2] and if necessary, implemented in conjunction with a health monitoring and stabilization program.
- Samples returned by the crew from uncharacterized or otherwise-untested areas of Mars should be considered as potentially hazardous, and should not be released from containment unless they are subjected to a sterilizing process, or until a series of tests determines that they do not present a biohazard.

### *3.3 Research & Development Tasks Related to OPS*

1. Describe the potential impacts on the near-field martian environment of human support activities expected in the operation of a human-occupied martian base (e.g., breathing oxygen, food supply, waste management, etc.) to determine the zone of contamination associated with a human landing, and the plausible limits of zones of no-contamination that can be preserved nearby.
2. Define the spatial dispersion of dust and human-associated contaminants on Mars by wind and other means.
3. Determine the survivability of Earth organisms and their component molecules in the ambient Mars environment, and in the conditions of the martian near-subsurface.
4. Examine future ALS designs and concepts with respect to planetary protection needs, especially with respect to organic and microbial contamination, to assess the potential effects of human activities in pressurized habitats and human-carrying rovers.
5. Examine future EVA designs (thermal control, gas control, material leakage) with respect to planetary protection needs, especially with respect to organic and microbial contamination, to assess the potential effects of human activities on the martian surface away from pressurized habitats and human-carrying rovers.
6. Develop AEMC technology required for life detection and potential pathogen detection within the habitat or EVA system, with a focus on sensitivity and specificity of tests needed to identify potential microbes of unknown origin.
7. Develop field-deployable systems to monitor human-associated biological contamination released into the martian environment (autonomous/automatic, rapid, reusable, and/or low-consumable recharge).

[2] The Earth-Moon system is considered as one biosphere for planetary protection purposes.

8. Determine how to conduct human-associated robotic operations on Mars to be consistent with planetary protection concerns, both for those robotic resources deployed independently during precursor missions and for those deployed in conjunction with human landings.
9. Define and develop planetary protection protocols for use on human missions. Develop and test methodologies for implementation of those protocols using Earth-based simulations (laboratory and field), lunar experience, and an improving knowledge of the martian environment based on precursor missions. Define and implement a training plan for the crew and other personnel involved with the mission.
10. Ensure that human factors research and design for human Mars missions will address biosafety considerations associated with planetary protection.
11. Provide robust and field-deployable systems to contain materials securely (wastes, propellants, etc.; for TBD durations) that may contaminate the martian environment.
12. Provide for containment of Mars samples within human-occupied spaces, and for those returned to Earth.
13. Develop mitigation techniques to deal with human-associated contaminants released on Mars and with contamination of human-occupied spaces by martian materials.

* * * * *

The individual OPS splinter group report was subsequently presented and discussed in a plenary session at the workshop along with reports from other splinter groups (see Appendix H for splinter group presentations). The plenary discussions led ultimately to set of integrated workshop conclusions and recommendations, and a list of combined R&D issues that need attention (see overall workshop findings and recommendations).

## Appendix A. References


Beaty, D.W., Snook, K., Allen, C.C., Eppler, D., Farrell, W.M., Heldmann, J., Metzger, P., Peach, L., Wagner, S.A., and Zeitlin, C., (2005). An Analysis of the Precursor Measurements of Mars Needed to Reduce the Risk of the First Human Missions to Mars. Unpublished white paper, 77 p, posted June, 2005 by the Mars Exploration Program Analysis Group (MEPAG) at http://mepag.jpl.nasa.gov/reports/index.html.

Criswell, M.E., M.S. Race, J.D. Rummel, and A. Baker, 2005. Planetary Protection Issues in the Human Exploration of Mars. NASA/CP-2005-213461

Des Marais, D. J., L. J. Allamandola, S. A. Benner, A. P. Boss, D. Deamer, P. G. Falkowski, J. D. Farmer, S. B. Hedges, B. M. Jakosky, A. H. Knoll, D. R. Liskowsky, V. S. Meadows, M. A. Meyer, C. B. Pilcher, K. H. Nealson, A. M. Spormann, J. D. Trent, W. W. Turner, N. J. Woolf, and H. W. Yorke (2003), The NASA Astrobiology Roadmap, *Astrobiology*, *3*, 219-235.

Hogan, J.A., M.S. Race, J.W. Fisher, J.A. Joshi, and J.D. Rummel, 2006. Life Support and Habitation and Planetary Protection Workshop: Final Report. NASA/TM- 2006-213485, NASA Ames Research Center, Mountain View, CA. (at the time of the workshop, only a summary version of the workshop was available. The full report was published later)

MEPAG (2004), Scientific Goals, Objectives, Investigations, and Priorities: 2003, Unpublished document, 22 p, posted April, 2004 by the Mars Exploration Program Analysis Group (MEPAG) at http://mepag.jpl.nasa.gov/reports/index.html.

National Research Council, Space Studies Board, 2002, Safe On Mars: Precursor Measurements Necessary to Support Human Operations on the Martian Surface. National Academy Press, Washington, D.C., www.nap.edu.

## Appendix B.  Program/Agenda

**Planetary Protection**
**Human System Research and Technology**
European Space Research and Technology Centre, The Netherlands

# AGENDA

### Day 1 – Thursday, 19. May 2005, Newton 1

| | | |
|---|---|---|
| 08:30 | Welcome and Workshop Overview | Gerhard Kminek<br>John Rummel |
| 08:45 | Introduction of Participants | All |
| 09:00 | Planetary Protection Requirements and Human Exploration | John Rummel |
| 09:30 | Report from the Pingree Park Workshop of 2001 | Margaret Race |
| 10:00 | Results of the NASA ALS-PP Meeting of 2005 | Jitendra Joshi |
| 10:30 | Coffee Break | |
| 10:45 | Human Missions to Mars—Scenario Options | Brenda Ward |
| 11:15 | ALS Considerations | Christophe Lasseur<br>Mark Kliss |
| 11:45 | EVA Considerations for Mars | Joseph Kosmo |
| 12:15 | Discussion | All |
| 12:30 | Lunch | All |
| 13:30 | Charge to Splinter Groups and Discussion of Tasks | All |
| 14:00 | Splinter Groups | All |
| 16:30 | Coffee Break | All |
| 16:45 | Interim Splinter Group Reports (20 minutes each) | Splinter Group Chairs |
| 17:45 | Discussion and Overview of 2$^{nd}$ Day | All |
| 18:00 | Reception | All |

## Splinter Group Assignments:

**Splinter Group 1: ALS; chair: Christophe Lasseur**
**Splinter Group 2: EVA; chair: Joseph Kosmo**
**Splinter Group 3: Operations and Support; chair: Brenda Ward**

## Day 2 – 20. May 2005, Newton 1

| | | |
|---|---|---|
| 08:30 | Splinter Groups Continue | All |
| 10:30 | Coffee Break | All |
| 10:45 | Splinter Groups | All |
| 13:00 | Lunch | All |
| 14:00 | Splinter Groups Report | Splinter Group Chairs |
| 14:30 | Consensus-Building Discussions | All |
| 16:30 | Coffee Break | All |
| 16:45 | Formulating Workshop Recommendations | All |
| 17:30 | Workshop Adjourn | All |

## Appendix C:
## Workshop Participants, Contact Information, and Original Assignments


**Andersen, D.**
SETI Institute
Center for the Study of Life in the Universe
43 Greenwood Street
Lake Placid NY 12946-1022
UNITED STATES
**Email:** dandersen@seti.org
**Phone:** +1 518-524-0993
**Fax:** +1 650-961-7099

**Beaty, D.**
Jet Propulsion Laboratory
Mars Exploration Directorate
4800 Oak Grove Drive
Pasadena CA 91109
UNITED STATES
**Email:** David.W.Beaty@jpl.nasa.gov
**Phone:** +1 818 354 7968
**Fax:** +1 818 393 3800

**Buxbaum, K.**
Jet Propulsion Laboratory
Mars Exploration Directorate
4800 Oak Grove Drive
Pasadena 91109
UNITED STATES
**Email:** Karen.L.Buxbaum@jpl.nasa.gov
**Phone:** +1 818 393 1135
**Fax:** +1 818 393 3800

**Clark, B.**
Lockheed Martin
Space Systems
POB 179, MS S-8000
Denver CO 80127
UNITED STATES
**Email:** benton.c.clark@LMCO.com
**Phone:** +1 303-971-9007
**Fax:** +1 303-971-2390

**Clervoy, J.F.**
ESA-EAC
HME-AA
139, route de Verneuil
78132 Les Mureaux cedex
FRANCE
**Email:** jean-francois.clervoy@esa.int
**Phone:** +49 7046 8049
**Fax:** +49 7046 8079

**Debus, A.**
CNES
18, avenue Edouard Belin
31 401 Toulouse cedex 9
FRANCE
**Email:** andre.debus@cnes.fr
**Phone:** +33 05 61 28 15 87
**Fax:** +33 05 61 28 31 82

**Eppler, D.**
SAIC
Mail Code OZ4, NASA-Johnson Space Center
Houston TX 77058
UNITED STATES
**Email:** dean.b.eppler1@jsc.nasa.gov
**Phone:** +1 281-244-8216
**Fax:** +1 281-244-8292

**Fisackerly, R**
ESA
D-HME
Ta 324
Noordwijk 2001AZ
NETHERLANDS
**Email:** Richard.Fisackerly@esa.int
**Phone:** +31 715658305
**Fax:** +31 715658305

**Heeg, P.**
Univ. Tuebingen
Inst. for Medical Microbiology
Elfriede Auhorn Str.
Tuebingen, 72076
GERMANY
**Email:** peter.heeg@med.uni-tuebingen.de
**Phone:** +49 7071 29 820 26
**Fax:** +49 7071 29 54 05

**Hoffman, S.**
Science Applications International Corporation
2200 Space Park Drive, Suite 200
Houston TX 77059
UNITED STATES
**Email:** stephen.j.hoffman@saic.com
**Phone:** +1 281 483 9264
**Fax:** +1 281 335 7291

**Horneck, G.**
DLR
Radiation Biology
Linder Höhe
Cologne, 51147
GERMANY
**Email:** gerda.horneck@dlr.de
**Phone:** +49 2203 601 4637
**Fax:** +49 2203 61970

**Hovland, S.**
European Space Agency
HME-MRH
Keplerlaan 1
2211 AG Noordwijk ZH
NETHERLANDS
**Email:** scott.hovland@esa.int
**Phone:** +31 71 5654023
**Fax:** +31 71 5654437

**Kliss, M.**
NASA-Ames Research Center
Bioengineering Branch, Life Sciences Division
M/S 239-15
Moffett Field CA 94035-1000
UNITED STATES
**Email:** mkliss@mail.arc.nasa.gov
**Phone:** +1 650 604 6246
**Fax:** +1 650 604 1092

**Kminek, G.**
ESA
HME-E
Keplerlaan 1
2200 AG Noordwijk
NETHERLANDS
**Email:** gerhard.kminek@esa.int
**Phone:** +31 71 565 6096
**Fax:** +31 71 565 8018

**Kosmo, J**
NASA-JSC
Crew&Thermal Systems Division/EC5
2101 NASA Road 1
Houston TX 77058
UNITED STATES
**Email:** joseph.j.kosmo@nasa.gov
**Phone:** +1 281 483 9235
**Fax:** +1 281 483 9167

**Lasseur, C.**
ESA
TEC-MCT
Keplerlaan 1
2200AG Noordwijk
NETHERLANDS
**Email:** christophe.lasseur@esa.int
**Phone:** +31 71 565 5100
**Fax:** +31 71 565 6142

**Lindner, R.**
European Space Agency, ESTEC
TEC-MMG
Keplerlaan 1
2200 AG
NETHERLANDS
**Email:** robert.lindner@esa.int
**Phone:** +31-71-5654678
**Fax:** +31-71-5655430

**Mani, P.**
tecrisk Ltd.
Biosafety
P.O. Box 298
3047 Bremgarten Berne
SWITZERLAND
**Email:** peter@tecrisk.com
**Phone:** +41 31 3055383
**Fax:** +41 31 3055384

**Marty, F.**
ESA-ESTEC
TEC-MCT
Keplerlaan 1
Noordwijk 2200 AG
NETHERLANDS
**Email:** Florence.Marty@esa.int
**Phone:** +31 715656613
**Fax:** +31 715656142

**McKay, C**
NASA Ames
Space Science Division
Mail Stop 245-3
Moffett Field CA 94035-1000
UNITED STATES
**Email:** cmckay@mail.arc.nasa.gov
**Phone:** +1 650 604 6864
**Fax:** +1 650 604 6779

**Pereira do Carmo, JP**
European Space Agency
TEC-MMO
Keplerlaan 1
2200 AG noordwijk
NETHERLANDS
**Email:** joao.pereira.do.carmo@esa.int
**Phone:** +31 71 5656169
**Fax:** +31 71 565 5430

**Race, M**
SETI Institute
515 No. Whisman Rd.
Mountain View CA 94043
UNITED STATES
**Email:** mracemom@aol.com
**Phone:** +1 925 947 1272
**Fax:** +1 650 960 7099

**Raulin, F**
LISA - CNRS & Univ Paris 7 & 12
Universite Paris 12
61 Avenue du General de Gaulle
F-94000 Creteil
FRANCE
**Email:** raulin@lisa.univ-paris12.fr
**Phone:** +33 1 45 17 15 58 / 6 08 3
**Fax:** +33 1 45 17 15 64

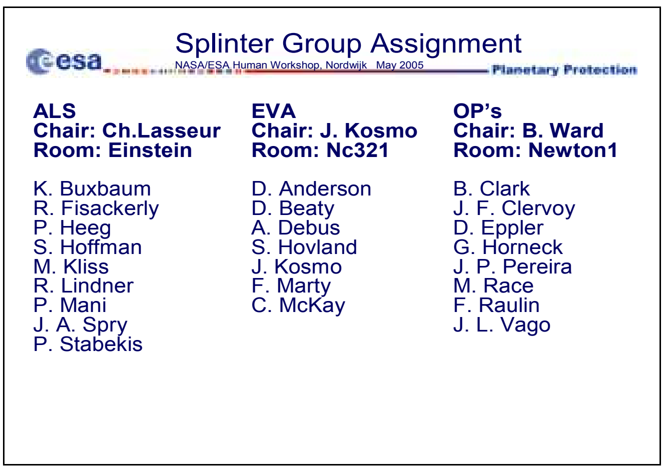
**Rummel, J.**
Science Mission Directorate
NASA Headquarters
Washington DC 20546
UNITED STATES
**Email:** jrummel@hq.nasa.gov
**Phone:** +1-202-358-0702
**Fax:** +1-202-358-3097

**Spry, J A**
The Open University
PSSRI
Walton Hall
Milton Keynes MK7 6AA
UNITED KINGDOM
**Email:** j.a.spry@open.ac.uk
**Phone:** +44 1908 652011
**Fax:** +44 1908 858022

**Stabekis, P.**
The Windermere Group
525 School St., SW Suite 201
Washington DC 20024
UNITED STATES
**Email:** pstabeki@hq.nasa.gov
**Phone:** +1-202-484-8247
**Fax:** +1-202-484-8251

**Vago, J. L.**
European Space Agency
MSM-GA
Keplerlaan 1
2201 AZ Noordwijk
NETHERLANDS
**Email:** jorge.vago@esa.int
**Phone:** +31 71 5655211
**Fax:** +31 71 5653661

**Ward, B.L.**
NASA/Johnson Space Center
Exploration
2101 NASA Parkway
Houston TX 77058
UNITED STATES
**Email:** brenda.l.ward@nasa.gov
**Phone:** +1 281-483-4657
**Fax:** +1 281-483-5800



## Appendix D: Tutorial Presentations

Pre-Workshop Tutorials:
D-1. Report on Pingree Park Human Missions Workshop, 2001 (Race)
D-2. Overview Report on NASA Human Mission Workshop at Houston, April 2005 (Joshi)
D-3. Advanced Life Support (ALS) findings from Houston workshop (Kliss)
D-4. Extravehicular Activities (EVA) findings from Houston workshop (Kosmo)

Workshop on Planetary Protection and Humans on Mars
May 19-20, 2005 ESA/ESTEC Noordwijk, Netherlands

2001 Pingree Park Workshop Summary:

# When Ecologies Collide? Planetary Protection Issues in the Human Exploration of Mars

In Press:

M. E. Criswell, M.S. Race, J.D. Rummel, and A. Baker
(Editors)

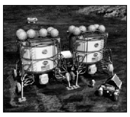
## Context and Summary

- **Consider Human Exploration and PP**
  Can it be done? Implications?
  2-day Workshop: Summer 2001, Pingree Park, CO
  Sponsor: NASA PP Office -- 29 Invited Experts
- **Conclude: Conceptually Possible**
  .... to develop systems, approaches and operational plans to enable safe, productive human missions in remote, hostile martian environments
- **PP *will* affect design, operations and costs**
  ... of life support, environmental and scientific systems



## Design and Operational Considerations

- **Human Health and Life Support Needs and Equipment** (Including EVA, Drilling, Monitoring Etc.)
- **Mitigation Procedures and Equipment**
- **Site and Regional Planning**
- **Back Contamination Controls and Procedures for Earth Return**

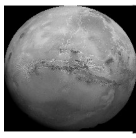




## Workshop Organization and Approach

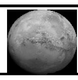
### Three Main Foci and 5 Subgroups

- **Protecting Mars and Science**
- **Protecting Astronauts & Health**
- **Protecting Earth From Back Contamination**
- **AND: Operations (2 Sub-groups)**





## Workgroup I: Protecting Mars



- **Areas of Special Biological Interest & Contamination Concerns**
  - ✓ **Landing Area and Features** (site with no martian life?)
  - ✓ **Space Suits**, Venting, Filtration, Monitoring
  - ✓ ? **Levels of Cleanliness and Cleaning**
  - ✓ **Understand Sources of Contaminants**
    (Spacecraft, Operations, Rover, Heat, Light Etc.)
  - ✓ **Possible Mixing of Microbial Communities** (identify potential contaminating microbial communities)
- **Classification of Sites** (Biological or Scientific Interest)
  - ✓ **Classes I-V** (based on probability of liquid water)
  - ✓ **Operational Zones of Contamination Control**
  - ✓ **Temporal and Sequencing Issues**
  - ✓ **Combined Human/Robotic Operations**



## Workgroup II: Protecting Human Health

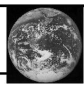
### Six Major Risk Topics

- **Physical/Health Status during long mission**
- **Human Behavior and Performance**
- **Biohazards**
- **Clinical Concerns** (injury, sickness, trace nutrients, etc.)
- **Human Activity and Contaminants**
  Physical & human wastes; Life support system effluents

### Points of Special Concern

- **Martian Dusts** (Human & Technological concerns)
- **Digging and Subsurface Operations**
- **Sample Handling and Testing on Mars**
- **Life Support System** (Suits, Habitats, Rovers, etc.)
- **Special Focus on Closed Loop Systems, Venting, Wastes**

## Workgroup III: Protecting Earth



### Containment &Contamination Avoidance:

- **Conservative Approach (like robotic missions)**
  - ✓ Isolation of Samples From Crew on Mars (Science & PP)
  - ✓ No Back Contamination If Not Exposed
  - ✓ Virtual Quarantine During Return Flight (Monitor Health)
  - ✓ If Breach of Containment, Mission Architecture Must Accommodate Quarantine and Transfer of Crew and Samples to Earth Containment Facility

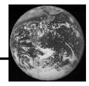
### Concept of Zoning for Human Ops

- **Inside Environments** (habitable 'areas')
- **Outside Environments**

  Characterized and Safe
  Characterized with Limited Access
  Uncharacterized with Limitations



## Workgroup III: Protecting Earth



### Safe Operational Zones (Biologically based)

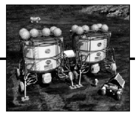
- Martian Dusts Pre-Cleared?
- Manage Ingress/Egress Systems; Cleaning
- Manage Boundary between Safe/Limited/Uncharacterized
- 'Isolate' Crew from Mars and Samples
- Break Chain of Contact with Mars

### Research and Development Needed

- Suite of Technologies for use on Mars to analyze environment
- Technology to limit exposure of crew and habitat to Mars
  - ✓ Robotic sampling
  - ✓ Tools for sampling and retrieval
  - ✓ Special transport containers, transfer ports, lab spaces, exam boxes etc.
  - ✓ Develop/Refine Suit Technology ('Exosuits'/Rovers, Suitlocks)
  - ✓ Cleaning and Maintenance Technologies
- Studies of Global Nature of Martian Dust
- Psychological Stress of Long Term Missions



## 2 Operations Subgroups



### Explored Six Scenarios for Issues of Forward and Back Contamination

1. Distant Surface Collection
2. Sample Analysis
3. ISRU at Base Area
4. Plant Growth Experiments/Greenhouses
5. Subsurface Sampling (10m vs.. 1 km)
6. Implications of Finding Life



## Operations Subgroup Scenarios

**1. Distant Surface Collection**

Pre-designated routes
Remote assessment prior to human exploration
Cleanable in situ; repair/maintain/decontaminate
New technology needs(suit leaks, monitoring, contamination, cleaning/decontam.)

**2. Sample Analysis**

Assume Life in Samples Until Proven Otherwise
Isolate Samples From Humans
Spill Containment/ Cleanup Procedures

**3. ISRU at Base Area** (Large Volume Issues)

Avoid Large Scale Impacts/disturbances
Equipmt.To Avoid Intro. of Haz. Materials & by-products
Understand Containment and Dust Dispersion
Non-invasive Assessment of Ground Ice
Not Depend on in Situ Water Resources Until Understand



## Operations Subgroup Scenarios

**4. Plant Growth Experiments/Greenhouses**

Concern About Potential 3rd Ecology
Special Concern Re: Releases From Greenhouses
Study and Manage Transition From Experiments to Food

**5. Subsurface Sampling (10km Vs. 1km)**

Need Technology for Drilling Remote Sites

**6. Implications of Finding ET Life**

Scientific, Technological and Societal Issues
Highly Scenario Dependent
Need Pre-established Procedures

**Surface Vs. Subsurface**
**Inside Vs. Outside**
**Extensiveness of Life Form**
**Temporal (Early or Late in Mission?)**



## TOP TEN FINDINGS AND RECOMMENDATIONS

- ✓ **Humans on Mars Bring Unique Capabilities**
- ✓ **Humans *Will* Bring Contaminants**
- ✓ **PP Controls Critical in All Mission Phases**
- ✓ **Nature of Martian Life, If Any, Unknown-- Possibly Extreme or Novel ?**
- ✓ **Robotic Precursor Information = Essential**

## TOP TEN FINDINGS AND RECOMMENDATIONS

- ✓ **Initially, Must Isolate Humans From Contact With Mars and Samples**
- ✓ **Need Categorize Martian Sites Based on Scientific Interest & Contamination Concerns**
- ✓ **More Study of Forward Contamination**
  Long-term Risks to Mars, “Colliding Ecologies”, Other Issues?
- ✓ **Consider General Human Factors**
  Debilitation, Reduced Performance, Unintended Actions
- ✓ **Improve Technology, Systems & Equipment for Exploration, Sampling and Base Activities**
  Especially Subsurface Sampling Operations



## Specific Areas of Research

- **Dispersion of Dust and Contaminants**
- **How Robotics Can Help Operations on Mars**
- **Site Classification System and Biological Plausibility Maps** **(Scientific Interest, Contamination Concern, Human Operations)**

---------------------------------------

- **Impacts of Human Support Activities**
- **Improve Suit Design (and Rovers)**
- **Technology for Life Detection and Monitoring of Pathogens/contaminants**



## Future Workshop Topics

- **“If Life, Then What?”**
  Implications of Different Discovery Scenarios
- **Communications with the Public**
  a. Response to Discovery of ET Life
  b. Planning to Prepare the Public for Possible ET
- **Human Health Issues, Life Support Needs, Work Environment , Psychological and Performance Factors**

Workshop on Planetary Protection and Humans on Mars
May 19-20, 2005 ESA/ESTEC Noordwijk, Netherlands

# Results of NASA LSH/PP Workshop

Life Support & Habitation and Planetary Protection Workshop

**Center for Advanced Space Studies**

**Houston, Texas, April 27-29, 2005**

Jitendra Joshi, NASA HQ

## Workshop Context

**Need for PP Requirements for Human Missions**

**Guide Design and Planning — Long Lead Time**

**Previous Studies:**

**1)** ***Planetary Protection Issues in the Human Exploration of Mars*** **(NASA 2001)**

**2)** ***Safe on Mars: Precursor Measurements Necessary to Support Human Operations on the Martian Surface*** **(NRC 2002)**

**Main Objectives of this Workshop:**

- ✓ **Initiate communication, understanding, and a working relationship between the Life Support and Habitation (LSH) and Planetary Protection (PP) communities**
- ✓ **Explore effect of PP policies and implementation on human life support, extravehicular activity and monitoring and control requirements for future human missions to Mars.**

- **35 Participants: Federal government, private companies and academia**
- **Areas Represented LSH: ALS, AEVA, AEMC and PP**



## Detailed Workshop Charter

1) Initiate communication, understanding, and a working relationship between the ALS, AEVA, AEMC and PP communities regarding the effect of PP policy development and implementation requirements for future human missions.

2) Define top-level PP concerns and issues associated with both forward and back contamination, and determine their likely effects on ALS, EVA and EMC hardware and operations for the first human mission to Mars.

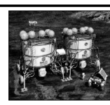
3) Identify PP requirements that will be needed to guide future technology development for ALS, EVA and EMC systems in advance of the first human mission.

4) Examine management approaches and that may be used to reduce the risk of developing systems prior to full definition of PP policies.

5) Identify important research areas and identify any gaps in science or technology capability that will help guide the development of technologies and approaches for ALS, AEVA, AEMC consistent with PP concerns regarding both forward and back contamination.



## Brief Overview of Workshop Focus Areas:



### ALS Program (including ISRU):

Supports the essential functions that sustain life including:

- Controlling cabin pressure, temperature and humidity;
- Regenerating air and water for safe use by humans;
- Managing wastes in a manner that cost effectively recovers resources;
- Supplying food, potentially including higher plant production.

### AEVA Program:

- Development of systems that provide reliable and safe mobile human life support (esp. suits and rovers)
- Systems capable of providing thermal, atmospheric and humidity control and protection from the external environment.



## Brief Overview of Workshop Focus Areas:

### AEMC Program

- Environmental testing technologies and control strategies to monitor the physical, chemical and microbial environment
- For both the human compartments and the life support systems (spacecraft and EVA)

### Planetary Protection (PP)

- Development, implementation and compliance with appropriate planetary protection policies for all US missions
- Based on Outer Space Treaty of 1967 and COSPAR policies
- Avoid forward and back contamination



## Workshop Approach/Organization

**Tutorials**

**General Breakout Groups (2)**

**Specialized Workgroups (4)**

**Plenary Discussions**

### Tutorial Topics:

- Advanced Life Support: Daniel J. Barta, NASA JSC
- Advanced Extravehicular Activity: Lara Kearney, NASA JSC
- Advanced Environmental Monitoring and Control: Darrell Jan, JPL
- PP Policy & Development: John D. Rummel, NASA HQ
- PP Implementation/ Robotic Missions:
  - Karen Buxbaum and Jack Barengoltz, JPL
- PP & Humans on Mars – 2001 Workshop: M.S. Race, SETI Inst.

## Throughout the Workshop:

### Three Foci for all Subgroups

- Protecting Mars and Science
- Protecting Astronauts & Health/Safety
- Protecting Earth From Back Contamination



## Key Starting Assumptions

- **Like robotic missions, human missions will need to take a conservative approach and assume that martian life exists until proven otherwise.**
- **No habitat or EVA system will be fully closed. Therefore missions carrying humans to Mars will contaminate the planet.**
- **The increased capabilities that human explorers can contribute to the astrobiological exploration of Mars exist only if human-associated contamination is controlled and understood.**
  - Critical to obtain evidence of past and/or present life on Mars well before these missions occur." (NRC, 1992).
  - Also: Essential to identify, characterize, minimize, and control contamination sources and pathways.
- **Safeguarding the Earth from potential back contamination is the highest planetary protection priority in Mars exploration.**
- **Crew and hardware on Mars will inevitably be exposed to martian materials. To the maximum extent practicable, these exposures should occur under controlled conditions.**
- **To decrease the potential for back contamination and mission costs, desirable to leave wastes and other contaminated materials on Mars upon mission completion.** Mitigation techniques include physical control over release (e.g., containment), active processing (e.g., sterilization) and/or passive exposure to martian adverse surface conditions to destroy life and biomarkers**.**



## General and Specialized Groups

**General /Specialized Breakout Groups (2)**

- Discussion: to provide an open forum where all participants can discuss issues within the various fields of expertise, thereby preparing themselves for more specific tasks associated with the Specific Breakout Groups.
- **Pivotal Focus:**
  Focusing on both forward and back contamination, define the top-level PP concerns and issues that are likely to impact various specific systems for human missions to Mars

**Specialized Sub-Groups (4): ALS, EVA, AEMC, PP**

- Each focused on assigned topics and questions covering:
  - **- Sources and Pathways for Fwd and Back Contamination.**
    (consider Mars & science, Astronauts, Earth contamination)
  - **- Potential Mitigation Approaches and current technology capabilities**
  - **- R&TD**
  - **- PP Topics and issues needing further definition**
  - **- PP areas with greatest cost/impact on mission/development**
  - **- Uncertainties/Open Issues**



## ALS and AEVA Subgroups– Details Later

**ALS Sub-Group (Mark Kliss)**

Task: Identify issues that could interface with PP within the seven program elements, namely: Waste Management, Water Recovery, Air Recovery, Food Systems, Thermal Control, Biomass Production and System Integration Modeling and Analysis.

**AEVA Sub-Group (Joe Kosmo)**

Task: Examine the influences of PP issues on the task of providing humans with portable life support systems and vehicular mobility. (suits, rovers, EVA's, exploration operations etc)



## Summary of AEMC Sub-Group Findings

Task: Identify and address the monitoring and control needs of human missions to Mars in relation to potential PP regulations

**WHAT TO MONITOR?** Viable microbial burden analysis

**Forward contamination:** PP currently includes culturable bacterial spores.
( Not currently include viruses, prions, eukaryotic cells.)
Start by use current approach for robotic forward contamination (Problem?)

**Back contamination : TBD**

**WHEN to Monitor?** AEMC Relevant to all missions phases–
prelaunch, transit, pre-use, surface operations, return, post-return

**WHERE:** Multiple Locations:
In the habitat, vicinity of habitat, rovers, suits, transit vehicle,

**WHAT TO DO ABOUT IT?**
Mitigation options (not usually a part of AEMC)
•Microbial reduction technology—might not always be feasible
•Quarantine zone



## AEMC Important Research /Technology Issues

- ✓ **Sensitivity Levels -** Much needs to be defined etc.
- ✓ **Considerable variation in time & effort required among the various methods, including preconcentration**
- ✓ **Technologies currently outside AEMC can be incorporated as appropriate**
  **Some are co-developed by Planetary Protection or Astrobiology**
- ✓ **EMC sensors & hardware systems as sources of potential contaminants**
  - e.g. cultured microbial burden, cells used in monitoring technology
- ✓ **Need to establish baseline due to presence of humans**
  - Inside habitat, outside, also inside/outside suits/rovers/etc.
  - Will sensors have adequate signal to noise ratio?
- ✓ **Facilities ALS & AEVA as contaminant source**
  - e.g. biofilms, microbial water processor
- ✓ **Response time required?**
  - Impacts mission operations, mitigation effectiveness

## AEMC Important Research/Technology Issues

- ✓ **Commonality & differences between AEMC/PP/Sci/Medicine**
  - E.g. all may need bacterial sensors, but have different bacterial targets
- ✓ **??? PP requirements for human mission**
  - Will human missions have same exposed surface requirement as robotic missions?
  - Will individual specs for rover, habitat, suit, tools, ISRU, etc. be required?
  - What is the allowable discharge from the suit, airlock, habitat, rover, etc.?
- ✓ **AEMC, PP, and Life detection Science needs and methods must be coordinated**
- ✓ **Unclear Who 'owns' the responsibility for monitoring to PP requirements? AEMC, PP, Science, all three?**
- ✓ **We don't know what the back contamination targets/levels are**
- ✓ **Containment Breach/Accidents can exceed PP requirements by many orders of magnitude—**impact needs to be understood



## PP Sub-Group Findings and Recommendations:

- ✓ There is no PP policy for human missions—Incremental Approach Needed (even PP policies for robotic missions are in flux)
- ✓ Focus on Replicating Biohazards (both Earth and Martian Life)
- ✓ Info from Precursor robotic missions and research will be essential
- ✓ Possible to outline a Conceptual Approach (not quantitative requirements) and provide preliminary guidelines for planners and designers of EVA, ALS, and EMC activities
- ✓ Early and regular coordination between the PP, scientific, planning, engineering, operations and medical communities is needed to develop workable and effective designs for human operations on Mars. (e.g., common needs for new technologies among planetary science exploration, human mission operations, and PP).
- ✓ Operations on the Moon may provide a relevant test-bed for many mission technologies, BUT… Must be in ways that feed forward to martian exploration
- ✓ Avoid going down two distinct and expensive technology pathways—one for the Moon and the other for Mars.



## PP Sub-Group Approach: Forward Contamination

**Humans = Unavoidable microbial carriers: Need Minimize cross contam. by design**

**Outbound Spacecraft—Cleanroom Assembly only (Class 100K)**

**On Planet: Landing Zone to be selected based on prior robotic evaluation**

—Must Verify as ZMBR

**Classification Systems -- Essential for science and operations --TBD**

**Guided by Emphasis on 'Special Regions'**

– strict separation of humans and sampling (like robotic)

–cleanliness requirements avoid the inadvertent introduction of Earth organisms or organic molecules into these environments (from astronauts or equipment; sterilize hardware involved with accessing special regions)

**Spacecraft, habitats and rovers shall filter material vented as gases (non-condensable), and shall not allow disposal of uncontained solids or fluids.**

**Special Research topics: Dusts, Food production, Biological treatment technologies (microenvironments); Extremophiles**

**Need Better Understanding of Unavoidable Human Contaminants (False Positives, biomarkers)**

**Need Focus on EMC—Inside & Outside (Life Detection technologies, sensitivity etc)**



## PP Sub-Group Approach: Astronauts & Back Contamination

**Microbial Contaminant Concerns Similar to Forward Contamination BUT… for Unknown (Martian) Organisms**

**Protecting Earth is Priority Concern**

**Concerns about Crew intimately linked with PP: Beyond traditional concerns about radiation, chemical and physical hazards, crew health/safety, accidents, etc)**

**PP Requirements will be developed based on Special Regions, Classification Systems, concerns about 3rd ecology, etc)**

**Requirement development will involve close collaboration with the scientific community, and better understanding of unavoidable levels of human-associated contaminants and their implications. TBD)**

**Quantitative guidelines and calculations for various zones will likely determine the tolerable levels of contamination allowed for particular aspects of human mission. Details TBD (work back from robotic standards)**

**Need Technology to Minimize Exposure- work with EVA, suits, rovers, and monitoring experts to develop technology to minimize exposure—TBD**



## PP Sub-Group Approach: Astronauts & Back Contamination

**Break Contact with Mars? (TBD)**

**Consider Possible Crew Exposure: Quarantine TBD**
**Must be available both on Mars surface and on Earth**

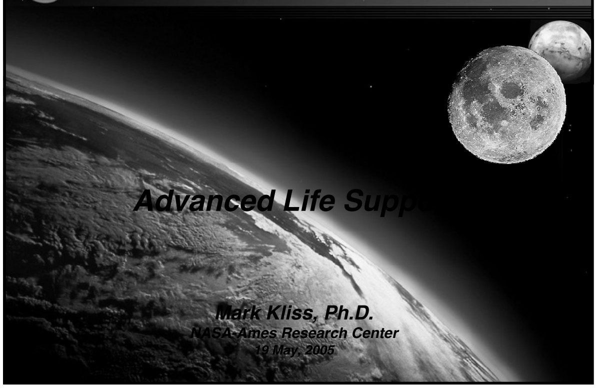
**Quarantine Protocol as well as Systems for Quarantine of Crew and Hardware = Significant System Drivers**



## The Big Picture: LOOKING AHEAD…..

- **Research and System Design Must Integrate PP From the Start**
- **Long Lead Time for Both PP Requirements and Systems**
- **PP Requirements Will Evolve in the Coming Years and Decades in Response to Numerous Factors (e.g. Rapid Changes in Scientific Information About Mars).**
- **Advisable to Involve Operations, Flight and Medical Experts**
- **Future Lunar Experiences Need to Be Designed As Relevant Test-bed for Mars PP**
- **Cannot Afford Two Separate System Approaches—moon Vs. Mars**
- **Need Coordinate With International Community (COSPAR, Partners, Standardization Etc.)**

## Life Support & Habitation
## Planetary Protection Considerations



# Advanced Life Supp

**Mark Kliss, Ph.D.**
**NASA-Ames Research Center**
**19 May, 2005**

## Advanced Life Support - Overview

- **Advanced Life Support**
  - Air Revitalization
  - Water Recovery
  - Thermal Control
  - Solid Waste Management
  - Advanced Food Technology
  - Crop Systems/ Biomass Production
  - Systems Analysis & Modeling
- ISRU
- Contingency Response
- Spacecraft Cabin & Habitats

- **Advanced Life Support represents a suite of enabling capabilities necessary to support human exploration missions.**
- **Advanced life support systems (including air revitalization, water recovery, thermal control, solid waste management, advanced food technology and crop systems) are key capabilities needed to significantly decrease the mass, energy and volume of future spacecraft and to decrease dependency on resupply.**
- **Key design aspects include "closing the loop" to recover usable mass; decreasing usage of expendables, energy, volume, heat rejection and crew time; utilizing *in situ* resources; and providing a high degree of reliability.**
- **Remote missions far from Earth will require additional contingency response capabilities for prevention and recovery from anomalies/events that may threaten mission success and crew safety.**



## Human Life Support Consumables & Wastes

| Consumables | Kilograms per person per day | | Wastes | Kilograms per person per day | |
|---|---|---|---|---|---|
| **Gases** | | **0.8** | **Gases** | | **1.0** |
| Oxygen | 0.84 | | Carbon Dioxide | 1.00 | |
| **Water** | | **23.4** | **Water** | | **23.7** |
| Drinking | 1.62 | | Urine | 1.50 | |
| Water content of food | 1.15 | | Perspiration/respiration | 2.28 | |
| Food preparation water | 0.79 | | Fecal water | 0.09 | |
| Shower and hand wash | 6.82 | | Shower and hand wash | 6.51 | |
| Clothes wash | 12.50 | | Clothes wash | 11.90 | |
| Urine flush | 0.50 | | Urine flush | 0.50 | |
| | | | Humidity condensate | 0.95 | |
| **Solids** | | **0.6** | **Solids** | | **0.2** |
| Food | 0.62 | | Urine | 0.06 | |
| | | | Feces | 0.03 | |
| | | | Perspiration | 0.02 | |
| | | | Shower & hand wash | 0.01 | |
| | | | Clothes wash | 0.08 | |
| **TOTAL** | | **24.8** | **TOTAL** | | **24.9** |

Quantities Variable – Largely Determined by Mission Requirements and MSIS
Quantities Fixed – Largely Determined by Basic Human Physiological Requirements



## Human Life Support Consumables & Wastes

**Examples of Other Consumables and Wastes**

- Trash, including food packaging, hygiene wipes and paper
- Make up gases for gases lost by cabin leakage
- Systems wastes: non-regenerable particulate filters and spent sorbants
- Thermal fluids consumed by evaporators, boilers & sublimators
- Gaseous, liquid and solid by-products from processors
- In-edible plant biomass
- Clothing
- Used medical supplies



## Human Life Support Technology Drivers

- Basic Human Life Support Requirements
- Manned Systems Integration Standards
- Specific Mission Requirements
  - Mission Location, Crew Size, Mission Duration
- Availability/Allocation of Spacecraft Resources
  - Volume, Mass, Heat Rejection, Power, Crew Time
- ISRU
- Planetary Protection Requirements
- Cabin Pressure
- Artificial Gravity
- Contingency, Redundancy and Spares
- Safety, Reliability, Maintainability, etc.
- Psycho-social Factors and Crew Preference



## Starting Assumptions

***PP considerations that will likely affect ALS design***

- Like robotic missions, human missions will need to take a conservative approach and assume that martian life exists until proven otherwise.
- Planetary protection concerns for human missions will have three foci:
  - Avoid forward contamination of Mars or interference with scientific exploration from terrestrially-associated microbial contaminants.
  - Protect astronauts from cross contamination or contact with Martian materials, whether inside or outside the habitat.
  - Break the chain of contact with Mars and avoid or minimize back contamination from the spacecraft, astronauts and materials returned to Earth.
- Even with the best design, no life support system and habitat will be fully closed.

  *Forward Contamination*
  - Human Mars missions will necessarily generate materials originating from both biotic and abiotic sources that could potentially contaminate Mars and/or be classified as an indicator of life.
  - A main objective is to identify, characterize, minimize, and control contamination sources and pathways. Policy and implementation will not likely reduce forward contamination to zero.
  - Strongly endorse the importance of classifying zones of biological, scientific, contamination and operational importance prior to and during human missions.

## Starting Assumptions
*PP considerations that will likely affect ALS design*

• Even with the best design, no life support system and habitat will be fully closed (continued).

*Back Contamination*

- Backward contamination is PP's highest priority. Although it will be all but impossible to completely break the chain of contact with Mars prior to Earth return for human missions, PP requirements will lead to rigorous design and development of ALS technologies in order to comply.

• Due to the increased potential for back contamination (as well as increased mission cost) by returning waste materials to Earth, it is desirable to have waste remain on Mars upon mission completion. There are three main mitigation approaches for risk management of wastes which could be used singularly or in combination:

1) physical control over release (e.g.,containment in canisters)
2) active destruction or transformation of the material (e.g., desiccation, oxidation, sterilization)
3) passive use of adverse surface environment for sterilization and/or destruction of material and biosignatures.

• Increasing the level of ALS system closure will enhance compliance with PP (and science) requirements due to the reduction of waste materials (solids, liquids and gases) and lower organic inventory that might otherwise require venting or discharge from the habitat.

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## Potential contaminants and pathways for ALS systems
*(with respect to forward and backward contamination)*

• ***Forward***

– Contaminants:
• Human Life Support System Wastes - human biota, food waste, wastewater brines, feces and wipes, medical wastes, clothing, paper, trash, tape, packaging, crop/plant material and associated microbiological communities, bioreactor contents (aerobic and anaerobic), inorganic materials that are evidence of biosignatures, construction materials, used hardware (orbital replacement units, filters, etc.).

• Thermal/Power Generation System Wastes - heat exchanger fluids, radiators, waste heat (melting of local ice).

– Pathways:
• Leakage from habitat, airlocks and other vessels - module, container, airlock, EVA, external tank and line, thermal systems, etc.

• Venting - nominal and contingency

• Surface storage and/or disposal of wastes - contained contents will inevitably be released at some point (level and duration of containment, and state of stored wastes must be determined).

• Unintentional discharges - equipment failures, micrometeor impacts, rupture of ISRU water line (or other fluid or gas line).

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## Potential contaminants and pathways for ALS systems
*(with respect to forward and backward contamination)*

• ***Backward***

– Contaminants:
• Martian life and martian material that serve as vectors of martian life (regolith, samples, dust?).

– Pathways:
• Initial entry into vessel:
EVA ingress and egress and tools, airlock-transferlock-dust lock, spacecraft docking mechanisms, externally used equipment, ISRU resource generation and use.

• Vessel internal transport mechanisms:
humans and other biological systems as vectors, airborne transmission/ventilation, contact transfer, internal systems transport (water lines, filters, etc.), sample handling.

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## Potential PP constraints placed on ALS systems

• Increasing closure of mass loops to minimize the amount of material that requires venting or discharge to the martian surface.

• Limiting certain kinds of operations or processes (e.g. venting or surface discharge).

• Necessitating that certain operations can be performed (e.g. sterilization).

• Restricting what types of processors can be utilized on a mission (e.g. no extremophiles).

• Creating needs for new capabilities/technologies (e.g. extended duration containment).

• Restriction of certain types of technologies (e.g. vacuum desorption of zeolite beds) or modifying their configuration (e.g. HEPA filters on all vent lines).

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## Specific examples of how PP requirements may affect ALS system design

• PP requirements will influence specific ALS technology development areas and system design. On-going technology development efforts and integrated system design may need to be modified, redirected, and/or accelerated, and new efforts may need to be initiated. Examples are provided in the following pages.

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| Air Revitalization System (ARS) Sub-capability | ARS Leading Technology Candidates |
|---|---|
| Control Carbon Dioxide Partial Pressure | Expendable chemisorbents (LiOH)<br>Vacuum swing adsorption - Venting Effects<br>Combined temperature/vacuum swing adsorption<br>Bioregenerative Systems |
| Control Humidity | Vacuum swing adsorption<br>Combined temperature/vacuum swing adsorption<br>Condenser with phase separation |
| Control Trace Atmospheric Components | Expendable adsorbents (activated charcoal)<br>Combined temperature/vacuum swing adsorption<br>Thermal catalytic oxidation ($CH_4$ and light VOCs)<br>Ambient temperature catalytic oxidation (CO and $H_2$) |
| Remove Suspended Particulate Matter | Macrofiltration (10 microns)<br>HEPA filtration (0.3 micron) - required for all vents?<br>Electrofiltration – (<0.1 micron)<br>Regenerative filters |
| Store & Distribute Nitrogen | High pressure storage and Cryogenic storage<br>Chemical storage |
| Generate, Store, & Distribute Oxygen | Cryogenic storage<br>Water electrolysis – solid polymer electrolyte<br>Oxygen transfer compressor (ORCA)<br>Bioregenerative Systems<br>From ISRU |
| Recover Resources | Carbon dioxide reduction (Sabatier, Bosch) Methane venting?<br>Carbon formation reactor (Sabatier post-processing) |
| Provide Ventilation | Fixed and portable axial fans<br>Ion discharge air movement systems<br>Low power low noise fans |

| Water Recovery System (WRS) Sub-capability | WRS Leading Technology Candidates |
|---|---|
| Urine Pretreatment | Organic acid<br>Increased water flush volume |
| Primary Treatment<br>(organic removal) | Rotating distillation process (combines primary and secondary treatment)<br>Biological systems - incubator for backward contamination?<br>Crop systems |
| Secondary Treatment<br>(Inorganic removal) | Membrane process<br>Rotating distillation system |
| Brine recovery | Distillation system<br>Membrane process<br>Disposal |
| Post-processing and disinfection | Low temperature catalysis<br>Photocatalysis<br>Photolysis<br>Ion exchange |
| Potable water storage | Silver<br>Residual requirement replaced with recirculating tank disinfection and point of use disinfection |
| Water Acquisition | ISRU - back contamination |

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| Solid Waste Management (SWM) Sub-capability | SWM Leading Technology Candidates |
|---|---|
| Volume reduction<br>Safening - Stabilization | Plastic heat melt compactor |
| Water removal and recovery<br>Safening - Stabilization | Lyophiliization- sterility? |
| • Water removal and recovery<br>• Safening - Stabilization | Air drying |
| Water removal and recovery<br>Safening - Stabilization | Vacuum drying |
| Volume reduction<br>Water removal and recovery<br>Safening - Stabilization | Pyrolysis - generation of biomarkers? |
| Volume reduction<br>Water removal and recovery<br>Safening - Stabilization<br>Resource recovery - nutrients | Incineration |
| Volume reduction<br>Water removal and recovery<br>Safening - Stabilization<br>Resource recovery - nutrients | Hydrothermal oxidation |

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| Solid Waste Management (cont'd) Sub-capability | SWM Leading Technology Candidates |
|---|---|
| Volume reduction<br>Water removal and recovery<br>Resource recovery - nutrients<br>Safening - Stabilization | Composting - aerobic |
| Volume reduction<br>Resource recovery - nutrients<br>Safening - Stabilization | Composting - anaerobic |
| Resource Recovery -clothes | Clothes washer |
| Containment | Containers- how strong, how long, how inert, venting? |

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| Thermal Sub-Capability | Thermal Technology Candidates |
|---|---|
| Heat Acquisition<br>• Provide cooling to avionics and other heat producing hardware<br>• Transfer energy from one fluid loop to another<br>• Provide temperature and humidity control for cabin air | •Composite Coldplate Shelf<br>•Fault Tolerant Heat Exchanger<br>•Porous Media Condensing Heat Exchanger; Vortex Dehumidification |
| Heat Transport<br>• Transport energy throughout the vehicle<br>• Provide heat rejection in hot Lunar environments<br>• Increased heat loads<br>• Requirements for assembly and maintenance during the mission | •Fluids that enable single loop systems<br>•Vapor Compression Heat Pump<br>•Low Power Two-phase ATCS<br>•none |
| Heat Rejection<br>• Provide radiant heat rejection<br>• Provide evaporative heat rejection | •Lightweight radiator; structural radiator<br>•Multi-environment evap; Contamination Insensitive Sublimator |

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| Food/Crop Capability (Level 4 CBS) | Food/Crop Leading Technology Candidates |
|---|---|
| • Robotic Lunar Mission Payload (CPS Component Testing) | • Transparent materials<br>• Regolith for crop rooting<br>• Remote operations |
| • Robotic Mars Mission Payload (CPS Component Testing) | • Transparent materials<br>• Regolith for crop rooting<br>• Remote operations<br>• Predeployment potential |
| • Production of Fresh Food for Surface (Prototype CPS) | • LEDs and $\mu$-wave sulfur lamps lighting<br>• Surface solar collectors and light conduits<br>• Recirculating hydroponics - incubator for back contamination?<br>• Salad and staple crop cultivars |
| • Production of Fresh Food for Transit (Operational Transit CPS) | • LEDs for lighting<br>• Transit solar collectors and light conduits<br>• Porous tube watering with or without media<br>• Dwarf salad crop cultivars |
| • Production of Fresh Food for Surface (Operational Surface CPS)<br>• Bioregenerative Integrated Crop Production System (ICPS) | • LEDs and $\mu$-wave sulfur lamps lighting<br>• Surface solar collectors and light conduits<br>• Recirculating hydroponics<br>• Salad and staple crop cultivars<br>• Mechanized / automated planting and harvesting<br>• Integrated crop / water system<br>• Integrated crop / air system |

## *Critical open issues/uncertainties relative to PP that affect ALS R&TD (unknowns)*

- Establishment of general PP requirements - general forward and back contamination requirements are needed for ALS development efforts.
- Restrictions on disposal of waste materials (gas, liquid, solid) - amount and composition of vented material, level and duration of containment, characteristics of disposed material; reversibility/recovery concept.
- Biomarker definition - which compounds are designated as biomarkers; what concentrations; particularly if hydrocarbons are included.
- Quantification of biomarker release limits - factors include biomarker longevity, potential for dissemination in atmosphere, EVA operations.
- Quarantining of crew and returning vessels - quarantine and decontamination procedures will influence ALS design and operation.
- Definition of the approach to control back contamination - acceptable levels and type of contamination at each link in the chain to prevent backward contamination are needed.
- Definition & identification of zones of min/max/ biological risk - minimizing potential for cross-contamination may allow for more relaxed ALS system requirements and vice-versa.

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## Discussion Results

- **Topics that require further research**
  - Increase efforts to quantify and characterize ALS system process streams (air, water, waste, etc.) to assist in assessing potential forward contamination risks, and in developing mitigation approaches. Determine the contribution of the martian environment (radiation, temperature) towards passive mitigation of forward contaminants.
  - Perform investigations to characterize contaminant releases from the cabin via leakage, intentional venting and general mission operations.
  - Identify pertinent air, water and waste management technologies for processing, containment, and disposal that comply with anticipated PP and science-based constraints (for surface and interplanetary space).
  - Perform system analyses to determine the viability of the surface waste storage concept for various waste processing scenarios.
  - Re-examine and modify ALS reference mission designs as necessary to harmonize with PP and science-based requirements.



## Discussion Results

- **PP requirements that impose the greatest ALS development costs**
  - Breaking the chain of contact for backward contamination - avoiding contamination of humans and returning hardware via multiple technological and operational steps. This may involve Mars surface, Mars orbit, transit, Earth orbit, and Earth surface activities.
  - Rigorous constraints on material releases to the martian environment, especially solid and liquid wastes. While venting of non-condensible gases may comply with PP requirements, scientific constraints may require substantial processing. Additional constraints may also be imposed upon thermal, food technologies, and biomass production systems.



## Discussion Results

- **Overall Recommendations for ALS and PP Considerations**
  - PP requirements will affect ALS system design, technology trade options and development costs. Development of PP requirements (initial bounds) for human missions should be accelerated, especially in the areas of discharge and disposal limits, backward contamination limits, and ISRU.
  - The ALS community should further define initial material inventory, process products and by-products, and release mechanisms associated with forward contamination. This information should be shared with the the PP and scientific communities early on to facilitate requirements generation.
  - Best estimates of available PP, scientific, and ALS requirements should be used to guide ALS technology development and selection. Employing conservative (stricter) requirements should be considered as a means to identify ALS systems which can meet both mission function and applicability needs (e.g. processes that can sterilize may have added value as compared to processes that cannot sterilize).
  - Perform systems analyses of mission scenarios using various ALS technology architectures to comply with predicted PP requirements early in the development process. Acknowledge this will need to be an iterative process.
  - Scientific limitation on release of hydrocarbon or other chemical/material designated as biomarkers will also likely affect ALS system design. Biomarker characterization and development of release limits is recommended.



## Back-up Charts



## Discussion Results

- **Identify plausible mitigation alternatives and obstacles for specific mission types and segments (e.g., transit, surface stay)**
  - For forward contamination:
    - Ventless life support processes, processing vented materials,
    - Containment and disposal approaches
    - Recycle, mineralize, stabilize, sterilize
    - Material selection and exclusion
    - Processor selection and exclusion (including biological, physical, chemical media).
    - Cleanliness operational procedures and technologies (cleaners, irradiators) and housekeeping. Includes prelaunch.
    - Operations and procedures (e.g. HACCP, hazmat, airlock operations, contingency response)
    - Design practices for minimum risk (including zoning or compartmentalizing and/or with independent controls and life support such as independent ventilation)
    - Monitoring and alarming
    - Design and interfaces with EVA and airlock and rover



## Discussion Results

**Identify plausible mitigation alternatives and obstacles for specific mission types and segments (e.g., transit, surface stay)**

(Continued)

- For Backward Contamination:
  - Containment and disposal approaches
  - Mineralize, stabilize, sterilize
  - Processor selection and exclusion (including biological, physical, chemical media).
  - Cleanliness operational procedures and technologies (cleaners, irradiators) and housekeeping. Includes prelaunch.
  - Design and interfaces with EVA and airlocks and Rover
  - Operations and procedures (e.g. HACCP, hazmat, airlock operations, contingency response)
  - Design practices for minimum risk (including zoning or compartmentalizing and/or with independent controls and life support)
  - Monitoring and alarming
  - Steps taken for vehicle transition from hypo gravity to microgravity transitions
  - Transfer of personnel and materials from contaminated vehicles to clean vehicles (e.g. ascent to transit). Consider storage of samples outside the habitation compartment

Life Support & Habitability and
Planetary Protection Workshop
April 27-29, 2005 Houston, TX

## Overview: EVA Considerations for Mars

Presented by J.Kosmo

Based on
Advanced Extravehicular Activity
Breakout Group Summary from LSH and PP Workshop

## AEVA Breakout Group - Participants

**Joe Kosmo/NASA-JSC, Lead**
**Carl Walz/NASA-HQ's**
**Sharon Cobb/NASA-HQ's**
**Dr. Anthony Hanford/Jacobs ESCG**
**Dr. Dean Eppler/SAIC**
**Alan Perka/NASA-JSC**

**External Contributors:**
**Dr. Steve Hoffman/SAIC**
**Amy Ross/NASA-JSC**
**Ed Hodgson/Hamilton Sundstrand Corp.**
**Dave Grazoisi/ILC Dover**
**Jack Bassick/David Clark Co.**

## Planetary Protection Advanced EVA – Specific Breakout Group Tasks

**Breakout Group charged with following tasks:**

- Identify potential contaminants and pathways for AEVA systems with respect to **forward** and **backward contamination**
- Identify **plausible mitigation alternatives and obstacles** for pertinent missions
- Identify **topics that require further research and technology development** and **discuss development strategies with uncertain PP requirements**
- Identify **PP requirements that impose the greatest mission/development costs**
- Identify **PP requirements/topics that require further definition**
- **Overall Recommendations**

## Purposes of Planetary Protection & Implications

**Forward Contamination**

**Assumption: - Missions carrying humans to Mars will contaminate the planet**

- **Protect mission science objectives :**
  - Unambiguous detection of past and present life
    - Implies avoiding biological and chemical contamination at science sites until science objectives achieved
      - » Need knowledge of transport and persistence of EVA released contaminants in planetary environment
      - » Evaluate representative EVA target measurements and sensitivity
    - Enable controlled experiments on transport / propagation / persistence of exobiology
  - Undisturbed study of surface geology / mineralogy in natural Mars atmosphere
    - Likely oxygen, and water vapor issues – potential alteration of samples
  - Uncontaminated samples for science in habitat and on return
- **Protect Mars life if found :**
    - For study
    - For survival

## Purposes of Planetary Protection & Implications

**Back Contamination**

**Assumption : - Humans will be exposed to Mars surface materials**

- Maintain livable / healthy environment in Mars surface habitat:
  - Avoid airlock contamination or isolate airlock
    - Separate "dust lock" or "suit port"
  - Avoid crew contamination & assure decontamination in suit don / doff ops.
  - Decontaminate sample containers, tools, instruments, before & during transfer into habitat
  - Contaminant control & removal capabilities in habitat
- Avoid risks to earth:
  - Decontamination capability for crew & all returning items
  - Sample isolation capabilities through life of mission
  - Sample / measure / observe test systems in ALS or others in habitat?
  - Implications of crew as test population – is long stay and early assured exposure desirable / essential? – How long & how much is enough?
    - Quarantine issues

## Potential Planetary Forward Contamination Pathways & Characteristics

- **Vehicle Landing Phase:** (S71-38189)
  - **Exhaust plume products and ejecta material**
    - Chemical contamination; Spores / viruses/ etc. on vehicle exterior surfaces – earth atmosphere exposure before & during launch is virtually guaranteed
    - Disturbance of surface region for x-radius distance
- **Habitat Deployment Phase:**
  - **Off-loading or Transport from Lander (if not integral to Lander)**
    - Autonomous/Robotic Mode:
      - Surface disturbance for x-radius
      - Vent & Material Composition products from robotic assisted operations
    - EVA-Assisted Mode:
      - Surface disturbance for x-radius
      - Vent & Material Composition products from human assisted operations
        - » $CO_2$, water vapor, trace contaminants due to suit/PLSS/airlock operations and leakage
- **Normal EVA Surface Operations Phase:**
  - **Routine daily/weekly activities**
    - Airlock operations
      - Vent gases, water vapor, trace contaminants, particulates, organisms in atmosphere
    - Transport to EVA worksites (2003e57386 & 2004-00408)
      - Surface disturbance for x-radius by rovers (both un-pressurized & pressurized vehicle systems)
      - Vent & Material Composition products
    - EVA surface traverses (2004e43512 & 2003e54766)
      - Surface disturbance for x-radius
      - Vent & Material Composition products
      - Suit surface, tool, & equipment contaminants from human contact in don / doff / servicing / maintenance – skin oils & acids, hair, dander, microbial…
  - **Geologic/Astro-biological sample collection activities (surface & sub-surface ops)**
    - All of the above concerns associated with human-assisted operations (2004e39632 & 2004e43534)
- **ISRU Operations Phase:** (2004e43567)
  - **All of the above concerns; perhaps magnified based on the extent of operations.**
  - **Venting / waste streams from ISRU operations – and contamination of those streams from equipment contact, human contact with ISRU systems, exchange with or back flow from habitat fluids.**

## Representative EVA-Associated Planetary Surface Forward Contamination

- **Airlock Operations**:
  - Based on ISS configuration (2-crewmember size)
    - Depress to 3.0 psia (20.7 kPa) and vent residual gas to space - (vent amt. ~ 2.0 lbs of gas per depress cycle)
    - Due to high power requirements & pump efficiency; planetary surface airlocks would operate similarly
  - Based on a "Minimum Volume" airlock (2-crewmember size)
    - Assuming volume is = 2X suited crewmember volume
    - Gas loss would be ~1/2 of the ISS case or 0.97 lbs. per depress operation
    - Minimum volume airlock will aggravate human contact contamination issues for don/doff and servicing operations unless a "Suit-port like" interface to the habitat is adopted.
- **Space Suit Operations**:
  - Total suit assembly leakage allocation based on representative Class I flight Shuttle EMU (each suit)

| | Ground-Level | In-Space Level |
|---|---|---|
| Arms (each) | 31.5 sccm/air | 9.0 sccm/O2 |
| Lower torso | 24.5 sccm/air | 7.0 sccm/O2 |
| Gloves (each) | 10.5 sccm/air | 3.0 sccm/O2 |
| Upper torso | 21.0 sccm/air | 6.0 sccm/O2 |
| Helmet | 7.0 sccm/air | 2.0 sccm/O2 |
| TOTAL LEAKAGE | 136.5 sccm/air | 39.0 sccm/O2 |

  - Additional leakage constituents from portable life support system (PLSS)
    - Vent system loop (connector fittings)
    - Oxygen supply source (gaseous or cryogenic)
    - Heat removal system (sublimator/water boiler; ~1 lb/hr.)
    - Potential venting during assisted operations, emergency operations, EVA recharge or equipment change-out activities
- **Additional Potential Contamination Constituents**:
  - Trace chemical contaminants associated with suit leakage ; Lubricants associated with surface support vehicles and suit bearings
  - Suit surface contaminants from habitat and human contact
  - Elastomeric/fabric materials from surface support vehicles and outer materials of space suit
    - Mechanical abrasion
    - Off-gassing of volatiles

## Representative Space Suit System Potential Leakage Path Areas

- Based on a modular constructed suit assembly for logistics interchangeability and commonality of components (represented by planetary prototype NASA-JSC MK III advanced technology suit) :
  - Identified approx. 50 separate potential leakage path areas represented by static seals, dynamic seals, and connector hardware pass-thru locations.
  - The potential suit leakage path areas include:
    - 30 individual modular element static seal interfaces
    - 15 individual bearing system dynamic seals
    - Rear-entry hatch closure seal area
    - 4 cryo-backpack connector hardware pass-thru locations
  - Does not take into consideration all individual gas bladder pattern heat sealed or adhesively bonded seams or natural permeation characteristics of the bladder material based on wear and abrasion
  - Given the above information, the robustness of the MK III suit is representative of the fact that after > 950 hrs. of pressurized use over the past 17 years, total leakage rates are on the order of 1,500 – 2000 sccm/min. after normal 40-hr. maintenance periods
    - This equates to current Class III Shuttle EMU suit leakage rates experienced during Neutral Buoyancy Laboratory (NBL) operations

## Trace Contaminants Produced By Humans
### (from Shuttle EMU Design & Performance Requirements Specification-SVHS 7800)

| Compound | Maximum Allowable Concentration PPM | Biological gm/human-day |
|---|---|---|
| Ammonia | 25 | 0.25 |
| Methane | 1000 | 0.047 |
| Acetaldehyde | 10 | 0.000083 |
| Acetone | 100 | 0.00013 |
| Ethyl Alcohol | 17 | 0.004 |
| Methyl Alcohol | 13 | 0.0014 |
| n-Butyl Alcohol | 3 | 0.0013 |
| Methyl Mercaptan | 0.1 | 0.00083 |
| Hydrogen Sulfide | 1 | 0.000075 |

- The above values represent trace contaminant human products that would be components of all space suit leakage and vent gases from airlocks/habitats.
- Various toxicological trace contaminant products and Spacecraft Maximum Allowable Concentrations for Selected Airborne Contaminants (SMAC's) developed by the National Research Council Committee on Toxicology can be found on web-site:
  - http://www1.jsc.nasa.gov/toxicology/SMACbooks.htm

## Trace Contamination Limitations
### (from JSC 20584; Spacecraft Maximum Allowable Concentrations for Airborne Contaminants)

- The **MAC** (Maximum Allowable Concentration) of Total Organics Exclusive of Fluorocarbons is 100 ppm Pentane Equivalents.

| A. Families of Compounds | Mole. Wt. | Units | MAC |
|---|---|---|---|
| 1.Alcohols (as Methanol) | 32 | mg/m3 | 10 |
| 2.Aldehydes (as Acrolein) | 56 | mg/m3 | 0.1 |
| 3.Aromatic Hydrocarbons (as Benzene) | 78 | mg/m3 | 3.0 |
| 4.Esters (as Methyl Butyrate) | 102 | mg/m3 | 30 |
| 5.Ethers (as Furan) | 68 | mg/m3 | 0.11 |
| 6.Halocarbons | | | |
| a. Chlorocarbons (as Chloroacetone) | 93 | mg/m3 | 0.5 |
| b. Chlorofluorocarbons (as Chlorofluoromethane) | 68 | mg/m3 | 24 |
| c. Fluorocarbons (as Trifluoromethane) | 70 | mg/m3 | 12 |
| 7.Hydrocarbons (as N-Pentane) | 72 | mg/m3 | 3.0 |
| 8.Inorganic Acids (as Hydrogen Fluoride) | 20 | mg/m3 | 0.08 |
| 9.Ketones (as Diisobutyl Ketone) | 142 | mg/m3 | 29 |
| 10.Mercaptans (as Methyl Mercaptan) | 48 | mg/m3 | 0.2 |
| 11.Oxides of Nitrogen (as Nitrogen Dioxide) | 46 | mg/m3 | 0.9 |
| 12.Organic Acids (as Acetic Acid) | 60 | mg/m3 | 5 |
| 13.Organic Nitrogens (as Monomethyl Hydrazine) | 46 | mg/m3 | 0.03 |
| 14.Organic Sulfides (as Diethyl Sulfide) | 90 | mg/m3 | 0.37 |

## Continuation of Trace Contaminant Limitations

| B. Specific Compounds | | Mole. Wt. | Units | MAC |
|---|---|---|---|---|
| 1. | Ammonia | 17 | mg/m3 | 17 |
| 2. | Hydrogen Cyanide | 27 | mg/m3 | 1.0 |
| 3. | Methane | 16 | mg/m3 | 3800 |

The MAC values represent the maximum total for a family of compounds and are based on the most toxic member of the family, except in the case of hydrocarbons (N-Pentane chosen for convenience of instrumentation calibration). Total is defined as the summation of compounds in a family. If measurements are made which will identify a specific compound, then a MAC value will be determined for the "known" compound. The "known" compound's measured concentration is subtracted from the family's "unknown" constituents which is then compared to the family MAC value. Until all members of the family are identified, the MAC value for the family of compounds will remain unaltered. See JSC 20584, Spacecraft Maximum Allowable Concentrations for Airborne Contaminants, for original specification source.

**C. Gas Sampling**

A gas sample shall be taken of the gas in the canister. The gas shall reside in the test item for 10± 1 minutes and then be drawn into an evacuated cylinder. Contaminants from the canister shall not exceed the following requirements:

| Name | Max. Allowed |
|---|---|
| Trichloroethylene | 0.1 ppm |
| Chloroform | 0.1 ppm |
| Methyl Chloroform | 0.1 ppm |
| Vinylidine Chloride | 0.1 ppm |
| 1.1.2.2 Tetrachloroethane | 0.1 ppm |
| Alcohol, Isopropyl | 5.0 ppm |
| Toluene | 3.0 ppm |
| Freon TF | 5.0 ppm |

## Potential Planetary Backward Contamination Pathways & Characteristics

- **Normal EVA Surface Operations Phase**:
  - Routine daily/weekly activities:
    - Airlock operations
      - Transport of dust & regolith materials from surface into airlock and subsequent habitat living areas
      - Crew contamination during don – inhalation / ingestion during EVA – inseparable transfer into habitat & to earth
    - Return from remote EVA worksites & surface traverses
      - Potential transport of "non-documented/classified " surface materials back into airlock/habitat living areas
  - Geologic/Astro-biological sample collection activities (surface & sub-surface ops)
    - Handling of samples (in-situ) or in habitat laboratory for analysis
  - Transfer of EVA prep / servicing / maintenance items into habitat
    - Surface contaminants trapped and captured in suit fabric folds & cavities, seal regions, porous materials, between layers, etc.
      - Limitations of practicable cleaning processes prior to airlock entry / in airlock
  - ISRU Operations Phase:
    - All of the above concerns; perhaps magnified based on the extent of operations

## Planetary Protection
## Plausible Mitigation Alternatives and Obstacles

- **Regarding Human-EVA Supported Surface Activities:**
  - Minimize surface contact area of initial human-EVA supported activities:
    - Use robotic precursors (tele-operated or autonomous mode) to scout & survey intended EVA worksite locations and potential science way-point stations prior to human intervention
      - Obstacle – may be the cost & time overhead associated with robotic vehicle operation; also, limitations associated with robotic vehicles as such (lack of real-time decision making, intuition and judgment)
  - Identify "safe" and "no-go" zones adjacent to and within x-radius distance of lander/habitat location for method of control for human-EVA supported traffic
      - Obstacle – may not be able to totally exclude "chance encounter" with "oasis-of-life"; potentially restrictive for critical surface operations (location of ISRU plant or power-plant distribution elements)
  - Reduce or eliminate EVA-system element contamination sources
    - Vent gases, leakages, trace chemical contaminants, material abrasion, etc.
      - Obstacle – not totally practical; through normal use and wear conditions over time, all potential contamination sources will increase and accumulate.

        Also a real restriction on life support technology choices.
  - Screen, identify and catalog all earth-based "signature" materials associated with EVA-system elements in order to recognize against potential "alien" life-bearing materials:
    - Develop "Contamination Materials Reference Guideline"
      - Obstacle – time and cost maybe excessively prohibitive; also, may not fully capture all associated materials and constituents
  - To potentially mitigate "backward" PP contamination, quarantine, isolate or discard all EVA surface-exposed hardware items (other than scientific samples) at habitat base-site as a "non-return" to Earth policy:
    - Provide "peel-off layer" over portions of suit to remove/discard prior to airlock entry
    - "Decontaminate" or stow (i.e., dust ante-room area) EVA hardware items prior to airlock entry
      - Obstacle – need to assess logistics and costs associated with "throw-away" versus "re-use" philosophy.
        - » Limited effectiveness given transfer of contaminants to crew and habitat

## PP EVA System Topics Requiring
## Further Research & Technology Development

- Improved space suit design features consistent with PP needs, especially for the demands of human activities on the Martian surface located away from pressurized habitats and rovers: (from ICES Tech. Paper No.2003-01-2523; "Planetary Protection Issues in the Human Exploration of Mars"
  - Define specific surface task activities that would require the implementation of appropriate PP measures
  - Potential modification or redesign of suit/PLSS venting systems applicable to Mars surface situations

- Describe and define the potential physical (chemical or biological) impacts that the identified suit/PLSS vent/leakage constituents would have in regard towards PP "forward" contamination concerns:
  - Determination of levels of control that are possible or needed for EVA systems; suits, PLSS, airlocks, rovers
  - Develop baseline information on release/escape of microbes from suits and airlocks and development of detection and monitoring sensors and procedures
  - Determine what effect would the natural Martian environment (UV, radiation, thermal, pressure) have towards "natural mitigation" of potential Earth-based contaminants (?)

## PP Requirements Imposing
## Greatest EVA Mission/Development Costs

- Definition of "Design-To" requirements is critical to understanding costs:
  - We have a pretty good idea of what we vent, and how much…what we don't know is what is acceptable and what isn't…
- The definition of "PP" needs in relation to how it impacts EVA mission & system element development costs should be considered and interpreted as follows:

  - Since EVA operations will have the most direct (wide spread) physical interaction with the Martian surface on a daily/weekly routine basis, "PP" needs should be considered in the following terms to mitigate hardware & operations costs:

**"Plausible Protection" Criteria**

1. Identify, quantify and catalog all potential EVA system contamination sources
2. Implement reasonable preventative measures (by combination of design and procedures) to reduce contamination sources that would be technically feasible and non-cost prohibitive
3. Screen and manage the contamination stream
4. Eliminate any unknown constituents –

   Given the intimate human interactions with suit systems including internal atmosphere composition, complexity and variability of the source, this may not be totally practical at a level that will protect science objectives. – It is not an unreasonable hypothesis that dominant contaminants in an earth life signature may also be top priority signatures in a search for Mars life.

## Overall EVA Systems PP Recommendations

- Define specific surface task activities that would require the implementation of appropriate PP measures
  - Need specific input to define tasks and requirements vs. PP measures
- Describe and define the potential physical (chemical or biological) impacts that the identified suit/PLSS vent/leakage constituents would have in regard towards PP "forward" contamination concerns
  - Conduct human suited subject chamber tests to determine actual products vented during suit operations
- Determine what levels of PP "backward" contamination control are possible or needed for EVA systems; suits, PLSS, airlocks, rovers
  - Develop appropriate operational protocol to minimize transfer of contamination products into the habitat
  - Consider the requirements associated with periodic inspection and maintenance, in order to maximize the time between inspection and minimize crew exposure to Martian materials
- Determine what effect would the natural Martian environment (UV, radiation, thermal, pressure) have towards "natural mitigation" of potential Earth-based contaminants (?)
  - Information on release/escape of microbes from suits and airlocks and development of detection and monitoring sensors and procedures
  - Develop tests based on human subject tests described above

## APPENDIX E: Splinter Group Objectives

Additional List of Objectives used by all splinter groups to guide and focus their deliberations during the workshop:

- Determine how planetary protection requirements will be implemented during human missions, and what standards of contamination control will apply to human explorers.

- Determine mission-specific planetary protection requirements:
  - Contrast initial human missions vs. later missions, if necessary.

  - Understand state-of-knowledge impacts on the design of human support systems, if possible.

  - Address the following specific questions related to Advanced Life Support (ALS) systems:
    - Will interplanetary disposal during transit be allowed, and what conditions will be imposed?
    - Will any waste be allowed to be stored or disposed of on/below the surface if adequately contained? If so, what level of containment would be sufficient? What would be the necessary characteristics of the waste? How long will containment need to be assured? What level of certainty is required (e.g., $<10^{-4}$)? Does the state of the waste need to be rendered so as to preclude serving as a substrate for biological growth (i.e., mineralized)? Will wastes be allowed to remain in the surface habitat after mission completion (or do they need to be contained on the surface or returned home)?

  - Will there be constraints as to what will be allowed to be returned to Earth (i.e., potential for back-contamination)? The inside of the returning spacecraft (?) may be contaminated to some degree from EVA interchange. This material will enter the solid, liquid and gas streams through various means. Therefore, how do we return home?

- Determine how internal habitat ALS technologies might affect the potential for planetary surface contamination (e.g., increased bioburden on suits and equipment, venting gases/liquids/particulates to planetary atmosphere via airlocks):
  - How "clean" do we need to be inside in order to support external PLANETARY PROTECTION requirements? Will ALS be involved with cleaning issues, or will someone else be tasked with that? Will ALS need to handle cleaning by-products?
  - Are there special measures that should be taken to avoid the propagation of extraterrestrial organisms in ALS systems? For example, if waste is stored "as-is", the waste could serve as a growth medium (if contaminated). The same is true for biological processors for waste, water and air.
  - What extent of gas venting (from habitats) will be allowed? What compounds will be allowed/excluded? Will particulate (microbial, organic, inorganic) control be necessary?

- Determine similar restrictions and requirements to be placed on human extravehicular activity (EVA) systems.

- Determine restrictions and/or required procedures to be emplaced for human activities and systems for use outside the habitat, particularly with respect to:
  - Subsurface access;
  - Use and/or distribution of fluids outside the habitat;
  - Planned or unplanned biological experiments or releases.

## APPENDIX F: Deliberative Exercise by EVA Splinter-Group

As part of their deliberations, the EVA subgroup used the future Phoenix mission as an exercise to focus on the implications of a revised zonation scheme under various situations on Mars.

*The paragraphs below provide information from that exercise and are indicative of the sub-group's thinking about a proposed zonation scheme.* ***No specific recommendations are implied from this hypothetical exercise.***

"…….By establishing special regions, COSPAR (2002) divided Mars into two zones of biological risk—special regions, and non-special regions. This is consistent with the principle proposed by the NRC (2002), that planetary protection planning work from zones of biological risk. For reference, according to COSPAR policy:

> *"A Special Region is defined as a region within which terrestrial organisms are likely to propagate,*
> *OR*
> *A region which is interpreted to have a high potential for the existence of extant martian life forms."*

<u>Possible Implementation Implications</u>

We submit that regions of global contamination risk need a much higher level of protection than regions of local contamination risk. As an example, consider the Phoenix mission, which has proposed accessing shallow ground ice in the great northern plains. This qualifies as a special region under current interpretation, and the mission has thereby been assigned a IVc classification. However, under the proposed 3-zone paradigm, if an acceptable case had been made that this mission's activities would contaminate only the immediate area of its activities, and that the biologic contamination could not spread either to a much larger volume of ground ice, or to a possible underlying aquifer, one could argue that the consequences of site contamination are acceptable. However, if alternatively we believed that contamination of the Phoenix site would spread, the consequences would be unacceptable, and preventive restrictions would need to be applied.

We would also need to take into consideration the uniqueness of the martian feature if one is proposed for local contamination as per Zone 2 above. It is incumbent on us as the protectors of future martian science to reasonably protect unique or rare martian geologic phenomena. For example, we have not yet discovered a geyser on Mars, and such features are exceeding rare on Earth. If one were identified on Mars, we would expect it to be explored with extreme care. Even if a case could be made that contamination would have local effect only (which in the case of this example would be impossible), we need provision to protect rare occurrences.

The current COSPAR Planetary Protection categories make a distinction depending on the mission objective (Cat. IVa vs. IVb), and the location on Mars (Cat. IVc). However, it would be illogical to send a Cat. IVb spacecraft (which by definition is designed to investigate extant martian life) to a non-special region (which by definition has low potential for extant martian life). As a practical matter, Category IVb missions will only be sent to locations that would qualify for protection under the provisions of Category IVc. Thus, in terms of location implications, IVb and IVc are rather closely linked (differing only in mission objective), and IVa is very different. In the hope of catalyzing future discussion, we have prepared the following thoughts regarding possible evolution of current policy using the three zones defined above:

1. Zone 1 (non-special regions) is the equivalent of what is today protected using Category IVa standards. This category is used for landing sites that have low biological potential. Landers to such places are allowed a significant bioburden of up to 300,000 viable, culturable microbial spores (at launch and on exposed surfaces). (Since viable non-culturable organisms will also be present, the total number of organisms on the s/c at launch is larger than this, but only a subset will still be alive at the time of martian landing). The community has already accepted that this sort of contamination does not have a global effect. Part of the reason this size bioburden is acceptable is because the martian surface is bathed in ultraviolet radiation, which kills most terrestrial microbes quickly (minutes). In addition, the martian surface is thought to be oxidizing, which also has a sterilizing effect. If a bioburden measured on the order of $10^5$ using our current metrics delivered to a contamination site has local effect only, how do we know that this would not also be true of a bioburden of $10^9$ microbes (or even higher)? Would these processes not equally well provide a natural mitigation for much larger bioburden? What scientific logic can be brought to bear to set a quantitative standard? The original figure was a capability-driven standard dating back to the time of Viking, but our capabilities and understanding of Mars have both changed since then. One important consideration for the establishment of contamination restrictions for this Zone is the degree of proximity to an adjacent Zone 2 or Zone 3, and the processes that would cause the contaminants to migrate there.

2. For Zone 2, biological contamination of the site is by definition of local extent only. An example of this may be contamination of a shallow drill hole into martian ground ice in a place where no communication to a global reservoir is possible. Keeping the drill hole and sampling operations clean and/or sterile enough to achieve a mission's scientific objectives must obviously be done, but this is quite independent of the final contamination state of the hole. From the perspective of forward planetary protection, we see no reason why the contamination threshold for this kind of situation cannot also be relatively high.

3. For Zone 3, the consequences of a contamination event are so severe that contamination thresholds must be set very low. We recommend either the equivalent of the Viking post-sterilization standard (which is used in Category IVc), or better."

## Appendix G: Glossary and Acronyms

| | |
|---|---|
| AEMC | Advanced Environmental Monitoring and Control |
| ALS | Advanced Life Support |
| Bioburden | The level of microbial contamination (total number of microbes or microbial density) in or on a spacecraft item of interest |
| COSPAR | Committee on Space Research - the international body responsible for formulating planetary protection policies in accordance with the Outer Space Treaty |
| ESA | European Space Agency |
| EVA | Extravehicular Activity |
| Human Factors | A variety of factors (behavioral, physiological, psychological etc) that may be of importance in the proper or successful implementation of planetary protection controls during human missions |
| ISO 8 | Cleanliness standard set by International Organization for Standardization--standards are based on the number of particles per cubic meter at a specified particle size; ISO 8 is equivalent to Class 100K Cleanroom. |
| ISRU | In-Situ Resource Utilization |
| MEPAG | Mars Exploration Program Analysis Group |
| NASA | National Aeronautics and Space Administration |
| OPS | Operations and Support |
| R & D | Research and Development |
| Special Regions | COSPAR-designated regions of planetary protection concern on Mars—Defined as areas where terrestrial organisms are likely to propagate *or* that have a high potential for the existence of martian life forms. The Mars special region definition used in this report is based on the COSPAR definition as per COSPAR policy of 20 October 2002, and amended on 24 March 2005. |
| TBD | To Be Developed/To Be Determined |
| ZMBR | Zone of Minimum Biological Risk |

## Appendix H:  Splinter Group Presentations

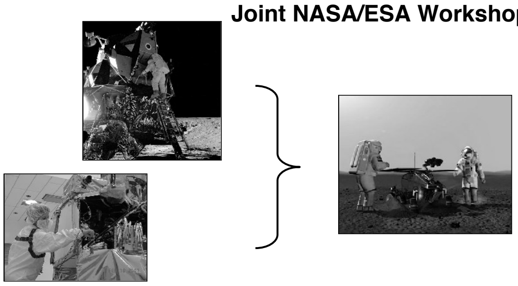
### H-1. ALS Splinter Group Presentation

### H-2. EVA Splinter Group Presentation

### H-3. OPS Splinter Group Presentation

esa Planetary Protection

**Mars Planetary Protection and Human Systems Research and Technology Joint NASA/ESA Workshop**



## Splinter Group Assignment

esa Planetary Protection

**ALS**
**Chair: Ch.Lasseur**
**Room: Df304**

R. Fisackerly
P. Heeg
S. Hoffman
M. Kliss
R. Lindner
P. Mani
J. A. Spry
P. Stabekis

## Background

esa Planetary Protection

Principles:

•Planetary protection (PP) requirements should be based on a thorough knowledge of potential contamination pathways and characteristics, and a current understanding of the biological potential of Mars.

•The Mars robotic precursor program will attempt to establish the presence or absence of human-affective biohazards on the Martian surface, and establish sufficient information to determine Zones of Minimal Biological Risk (ZMBRs) as recommended by the US National Research Council (*Safe on Mars*, 2002).

Top level workshop goal:

Determine how PP requirements will be implemented during human missions, and what standards of contamination control will apply to human explorers.

## Splinter Group Tasks

esa Planetary Protection

Framework:

•Contrast initial human missions vs. later missions, if necessary;

-Early missions have greater perceived risk, but:

-PP requirements will not get easier in later missions. No distinction made between initial and later human missions other than application of "lessons learned"/be more informed by first missions.

•Understand the impact on the design of human support systems.

-Design with the approach to limit leakage/contamination to tbd levels, bearing in mind that closed systems are the ideal.
(determination of "tbd" is an iterative process with inputs from multiple research expertise areas)
-Sterilization/decontamination capabilities will be required, both for waste, volumes (habitat, labs) and equipment.

## Splinter Group Tasks

esa Planetary Protection

•What is the overall approach to contamination control?
- Including forward and backward contamination levels (e.g., zones of
- contamination control);

5. Quantitative requirements shall be derived based on protection of special regions, and applied as follows:

No quantitative bioburden requirements should be applied to landing systems or habitats, other than cleanroom assembly

Additional cleanliness requirements may be necessary pending more information on:

•The generation of additional (post launch) human-generated contamination (solids, particularly microbial, liquid).
•The transfer of this contamination and its effect on this and subsequent mission objectives

Quarantine requirements (crew and samples).
If there is a requirement for individual quarantine then separate ALS will be needed with the facility to test/evaluate.
No unique ALS capability is required for the quarantine of the whole crew.
The Earth entry segment of the mission would require a leak-proof ALS.

## Splinter Group Tasks

esa Planetary Protection

• Human missions to Mars, including associated missions to emplace assets (ISRU, ALS consumables) shall not affect or otherwise contaminate "special regions" of Mars, as defined in the COSPAR Planetary Protection Policy of October 2002

## Splinter Group Tasks

esa Planetary Protection

•What is the approach to waste & consumable management?

- Depending on the mission phase (e.g., transit, planetary surface);
  - -- Transits
    - -From a PP perspective, the best overall approach is to recover water, contain dry solids, and actively jettison waste such that it is never taken to the surface.
    - -Any active jettisoning must be done in such a way that the outside surfaces of the spacecraft are not contaminated.
    - -If brought to the surface, containment and/or sterilization is required.
  - -- Surface
    - -Long Stay (300 day) - containment and/or sterilization ; leave on surface
    - -Short Stay (30-60 days) - containment and/or sterilization and leave on surface
    - -Decontamination of the habitat is required prior to leaving the planet.
- -Depending on the type of waste & consumable (different levels of various contaminants and dispersion properties).
  - -- No differentiation. Assume high burden on everything and use an overkill approach.

## Splinter Group Tasks

esa Planetary Protection

•What are the off-nominal events that could potential lead to contamination of Mars or the terrestrial biosphere?

-Identify the consequences and suggest mitigation strategies.

-Breach of containment, failure of decontamination systems, death of crew, exposure to Mars environment
-Mitigation strategies include design practices for reducing risk, operations and procedures for contingency response.

## Splinter Group Tasks

esa Planetary Protection

-What is the R&D required to cope with PP requirements?

-Including robotic pre-cursor missions.

–On-line, real time genetic identification of biological organisms in ALS.

–Development of near field and far field models for contamination transport to guide adequacy of PP requirements for human missions.

–Increase efforts to quantify and characterize ALS system process streams (air, water, waste, etc.) to assist in assessing potential forward contamination risks, and in developing mitigation approaches. Determine the contribution of the martian environment (radiation, temperature) towards passive mitigation of forward contaminants.

–Perform investigations to characterize contaminant releases from the cabin via leakage, intentional venting and general mission operations.

–Identify pertinent air, water and waste management technologies for processing, containment, and disposal that comply with anticipated PP and science-based constraints (for surface and interplanetary space).

–Perform system analyses to determine the viability of the surface waste storage concept for various waste processing scenarios.

–Re-examine and modify ALS reference mission designs as necessary to harmonize with PP and science-based requirements.

# DISCUSSION NOTES, BREAKOUT GROUP #2 (EVA SPLINTER GROUP)

**Joe Kosmo, David Beaty, Andre Debus, Chris McKay, Dale Andersen, Scott Hovland, Gerhard Kminek**



## Assigned Questions

1. What is the overall approach to contamination control?
2. What is the approach to waste & consumable management?
3. What are the off-nominal events that could potentially lead to contamination of Mars or the terrestrial biosphere?
4. What is the R & D required to cope with PP requirements?



## Assertions

1. The pursuit of our general scientific objectives related to searching for indigenous life on Mars is steadily progressing towards an understanding that **for scientific purposes**, protecting all of Mars equally is not necessary. Some parts of Mars need much higher protection than other parts, and as our knowledge increases, we will be able to recognize spatially dependent variations in our protection needs.
2. It does not make sense to have separate PP policies for human and robotic missions. The reasons for protecting Mars and Earth are independent of mission implementation. We need one policy with which all missions comply.
3. It is impossible for a human mission to be designed in accordance with the provisions of Category IVa, currently the least restrictive PP category. Without a relaxation of current PP restrictions, a human mission to Mars cannot be done.
4. It will be impossible to avoid exposure of human crewmembers who land on the Martian surface to Martian materials.
5. We need to have a viable approach for returning crew members to Earth, even if they have been infected with Martian organisms.



## Forward PP Conceptual Approach

The current concept of special region needs to be sub-divided, resulting in three zones with different protection needs.

- Non-special region. A site for which contamination is allowed; **growth or propagation are unlikely,** and the site is not of intrinsic interest for life detection. Implementation of the current PP policy needs to be updated (implementation of the policy for human exploration needed).

Special region

- Region of local risk. A site of astrobiology interest where a biological contamination event has local (but potentially remeditatable) effects only. No global propagation.
  - PP requirements are relative (can be traded off against engineering)
- Region of global risk: A region within which biological contamination has the potential to spread in a global sense, and no remediation is possible.
  - These need to have a hard protection. PP requirements are absolute.

All of the above sites are potentially accessible by astronauts using proper tools and techniques.



## Back PP Conceptual Approach

**Intent: Return missions (robotic AND human) must not be hazardous to Earth's biosphere.**

- Implementation Option 1. All Martian material contained or sterilized. Breaking the chain of contact is achievable by robotic missions, but this is not practical for nominal human missions.
- Implementation Option 2. Prior missions have established site is not hazardous (but not necessarily dead); breaking the chain of contact not required. This will involve both robotic missions and early human missions feeding forward to later human missions.
  - Contingency Capability Required: Empower the astronauts to respond to possible unexpected indications of extant life and/or possible exposure. The mission will need the tools and training to assess and control possible Martian biology if encountered.
    - On-board capability to detect and understand hazard
    - Sterilization capability (method shall be effective)
    - Personnel isolation capability
  - Emergency procedure if a hazard is discovered: We need to have a plan for returning astronauts to Earth, even if they have been contaminated by Martian life.
    - Need emergency crew transfer capability to quarantine facility on Earth.



## Question #1: Approach to Contamination Control

***Forward PP***

| | |
|---|---|
| Non-special region. | Evolution of current IVa implementation. No extant life science investigations included. Primary purpose of contamination control standards is to avoid contamination of adjacent special regions. Current standards can be relaxed significantly. |
| Region of local risk. | Evolution of current IVb implementation (protection of extant life detection experiments). Allow for contamination of the site visited, even though it has biological interest. Intent is to protect the life science (aseptic sampling techniques, sample transfers, etc.), but not necessarily the local environment. Need to consider the uniqueness of the site to be visited. |
| Region of global risk | Amplification of current IVc implementation. Intent is for protection of both the life science and the globally communicative environment (highest contamination control standards). Off-nominal events could be catastrophic, and must be planned for. (Two examples are rabbits in Australia and the Europa sub-ice ocean.) |

## Back-ups

- The following notes were recorded during the discussions of the break-out team May 19-20, 2005 but were not judged to useful enough to incorporate into our text report.



## Question #1: Approach to Contamination Control

***Back PP***

- Humans will be exposed to Mars surface materials
- Backward contamination pathways exist during normal EVA surface ops
  - Airlock operations
    - Transport of dust & regolith materials from surface into airlock and subsequent habitat living areas
    - Crew contamination during don – inhalation / ingestion during EVA; inseparable transfer into habitat & to earth
    - Return from remote EVA worksites & surface traverses
    - Transport of "non-documented/classified " surface materials back into airlock/habitat living areas
  - Geologic/Astro-biological sample collection activities (surface & sub-surface ops)
    - All of the above concerns associated with human-assisted operations
    - Handling of samples (in-situ) or in habitat laboratory for analysis
  - Transfer EVA prep / servicing / maintenance items into habitat
    - Surface contaminants and contaminants in cavities, seal regions, porous materials, between layers, etc.
    - Limitations of practicable cleaning processes prior to airlock entry / in airlock
  - ISRU Operations Phase:
    - All of the above concerns; perhaps magnified based on the extent of operations
- Issues with back contamination breaking the chain. Do we have to know in advance that there is a biological hazard ?



## Question #1. Discussion notes

- Need to separate biological, non-biological, and organic material—non-biological doesn't matter.
- Organic contamination is a separate issue—is this a science issue, not a PP issue? What is the boundary between science and PP? How will the projects deal with this? PP requirements have higher priority than science. How does the survival/health of the crew relate to this?
- How will the contamination be diluted? Or self-remeditated? UV? We have insufficient information.
- What is the rate of decomposition of bio-load delivered to Mars, and the rate of its dispersal on Mars due to natural processes?
- How can we know that a region is 'local' rather than 'global'?
- To allow access to special regions, we need tools to do aseptic clean sampling, and means to do sterilization.
  - We need the tools and techniques.



## Question #1. Discussion notes

- Don't try for zero release and 100% containment.
- Contact w. Martian material results in back contamination—they become a vector of contamination.
- How will we control the contact of astronauts with Martian material?
- Issues with back contamination, breaking the chain. Do we have to know in advance that there is not biological hazard?
- ISRU—subsurface contamination, discovery of life while digging.
- To what extent is the zoning concept is useful? Can it be qualified with the precursor missions?
- No matter what the issue is, we have to have a way to bring the crew home.
- Will there be a quarantine procedure as a default, or only for use if there is cause? Will it be an emergency procedure?



## Question #2: Waste and Consumable Management

- Safe storage containment and monitoring for control of waste products :
  - Potential use of waste products for future re-cycling needs
  - Storage period TBD dependent upon requirements and technology for re-cycling use



## Question #2. Discussion Notes

- If you release something, how much is it compared to the volume? What detection limits will be design to?

## Question #3: Off-nominal events

- ISRU subsurface operations; discovery of life while digging ?
- In a contingency situation, crew safety is first.
- No matter what the issue is, we have to have a way to bring the crew home:
  - Dead, alive; sick or injured



## Question #3. What are the off-nominal events . . . ?

- What will happen in a contingency situation? Crew safety is first.
- How to deal with a sick astronaut on the way home?
- How will we manage the astronaut quarantine, with respect to the discovery of something positive?
- What to do if we get positive information about martian life during the course of the mission?



## Question #4: R & D required to cope with PP requirements

- **Define specific surface task activities that would require the implementation of appropriate PP measures**
- **Potential modification or redesign of suit/PLSS venting systems applicable to Mars surface situations**
- **Describe and define the potential physical (chemical or biological) impacts that the identified suit/PLSS vent/leakage constituents would have in regard towards PP "forward" contamination concerns:**
  - **Determination of levels of filtration that are possible or needed for EVA systems; suits, PLSS, airlocks, rovers**
  - **Information on release/escape of microbes from suits and airlocks and development of detection and monitoring sensors and procedures**
- **Determine what effect would the natural Martian environment (UV, radiation, thermal, pressure) have towards "natural mitigation" of potential Earth-based contaminants (?)**



## Question #4. What is the R&D required to cope w. PP requirements?

- There are issues with mutations.
- Would an in-situ biological test (plants or animals) be valuable? Need reduced gravity, radiation, etc.
- We need sample return.
- Need to be able to do in-field sterilization (of tools!) May need special suits for aseptic collection.
- Give the humans tools to deal with the problem.
- Accept that the system isn't perfect—can't be engineered a priori to meet current public risk standards.



## Prototype Future Planetary Protection Requirements

1. Future missions to Mars (both human and robotic) shall not contaminate "special regions" of Mars, as defined in the COSPAR Planetary Protection Policy of October 2002, and as further sub-divided by this report (local and global), beyond the thresholds described below:
   a) For regions of "local contamination risk", contamination events may not exceed the standards currently described by Category IVa. In proposing that a mission's activity will have local effect only, a proposing project must demonstrate that any nearby regions of global contamination risk will be sufficiently safe.
   b) Permission to access (and contaminate) scientifically unique special regions of local contamination risk shall be granted only with the concurrence of TBD international scientific organization.
   c) For regions of "global contamination risk", contamination events may not exceed the standards currently described by Category IVb.



## Prototype Future Planetary Protection Requirements

2. Quantitative requirements shall be derived based on protection of special regions, and applied as follows:
   a) No quantitative bio-burden requirements shall be applied to systems or habitats landing in "non-special regions", other than clean room assembly
   b) Spacecraft, landers, habitats, and rovers shall (to the maximum possible extent) filter material vented as gases, and shall not allow uncontained disposal of solids or liquids
   c) Contamination associated with astronauts involved in EVA operations adjacent to special regions or involved in sampling them shall be controlled per the quantitative requirements
   d) Hardware elements involved with accessing special regions of global contamination risk shall be subjected to a sterilizing process either on Earth or on Mars.

## Prototype Future Planetary Protection Requirements

3. All operations of human missions to Mars shall include isolation of humans from directly contacting untested Martian materials. This implies:
   a) Since contact with Martian regolith and dust by human explorers is thought to be highly probable, one or more precursor robotic tests is required in order to be able to conclude that the first human landing site is acceptably safe.
   b) Human missions shall include a means of assessing the biohazards in adjacent untested areas (either subsurface, or nearby surface areas), along with a means for allowing controlled access to those areas.
4. The site classification system and a biological plausibility map of the Martian surface and subsurface, based on remote sensing data and on-mission testing, shall be employed during any mission to limit potential crew exposure to areas on Mars that might support Martian life.

Workshop report, EVA Group, May 19-20, 2005

## Prototype Future Planetary Protection Requirements

5. A quarantine capability for both the entire crew and for individual crewmembers shall be provided during the mission, in case uncontrolled contact with a Martian life-form occurs. Basic tests of the medical condition of the crew and their potential response to pathogens or adventitious microbes shall be defined, provided, and employed regularly on the mission.
6. A quarantine capability and appropriate medical testing shall be provided for the crew upon return to the Earth (Moon or Earth-orbit) and implemented in conjunction with a health stabilization program.
7. Samples returned by the crew from uncontrolled or otherwise-untested areas of Mars shall be considered as potentially hazardous, and shall not be released from containment unless they are subjected to a sterilizing process, or until a series of tests determines that they do not present a biohazard.

Workshop report, EVA Group, May 19-20, 2005

## ESA/NASA Workshop:
## Ops Splinter Group –

## Recommended Planetary Protection Requirements for Humans on Mars

ESA-NASA PP Workshop
May 2005

## Ops Group Report

- Contrast initial human missions vs. later missions, if necessary;
  - Due to the time constraints associated with the requirement to certify the landing site as a zone of minimum biological risk (see below), it is anticipated that there will be a requirement for a precursor sample return mission from the human landing site to support the execution of short (30-day) Mars missions of the conjunction class
- What is the overall approach to contamination control?
  - See requirements set

## Overall Policy Requirements (Level 0)

- Planetary protection shall be considered a critical element for the success of human missions to Mars
- Evaluation of planetary protection requirements shall be considered in all human Mars mission subsystems development
- Planetary protection considerations shall be included in human Mars mission planning, training, operations protocols, and mission execution.

## Assumptions

- The greater capabilities of human explorers can contribute to the astrobiological exploration of Mars only if human-associated contamination is controlled and understood.
- It will be not be possible for all human-associated processes and mission operations to be conducted within entirely closed systems.
- Crewmembers exploring Mars will inevitably be exposed to martian materials. To the maximum extent practicable, these exposures should occur under controlled conditions.
- Safeguarding the Earth from potential back contamination is the highest planetary protection priority in Mars exploration.

## Conceptual Approach

- Human missions to Mars shall not affect or otherwise contaminate "special regions" of Mars (as defined in the COSPAR Planetary Protection Policy of October 2002), nor be contaminated by materials from them
  - Mission (orbiter, lander, rovers, crew, instruments, and tools) cleanliness and containment requirements shall be determined in such a way as to avoid the inadvertant introduction of Earth organisms or organic molecules into these environments, and the inadvertant exposure of human explorers to material from these regions.
  - Landing site selection and operational accessibility to scientifically desirable special regions (including prime access to ISRU-important subsurface ice or water) shall be directly traded against the microbial or organic cleanliness of human-associated (or robotic) systems supporting the missions.
- Calculations based on this approach will determine the allowable levels and kinds of contamination allowed for specific aspects of any particular human mission.

## Definition of COSPAR "Special Region"

A Special Region is defined as a region within which terrestrial organisms are likely to propagate,

**OR**

A region which is interpreted to have a high potential for the existence of extant Martian life forms.

Given current understanding, this is applied to regions where liquid water is present or may occur. Specific examples include, but are not limited to:

- Subsurface access in an area and to a depth where the presence of liquid water is probable
- Penetrations into the polar caps
- Areas of hydrothermal activity

[This designation may apply to large areas of Mars, depending on factors currently unknown.]

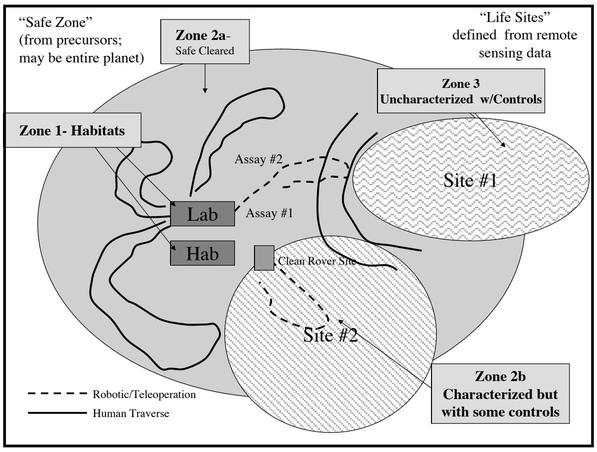
# PP General Issues

1. Planetary protection risks are among the many risks to be identified and evaluated together—then reduced, mitigated, or eliminated when possible to enable mission success.
2. General human factors need to be considered along with planetary protection issues for a human mission to Mars.
3. A crewmember onboard the mission should be given primary responsibility for the implementation of planetary protection provisions affecting the crew during the mission.

# Forward Contamination

1. Human mission planning, including landing site selection, base location, and mission objectives, should follow from precursor robotic information and evaluations made at those sites and/or from information developed from a sample return mission or missions.

2. Definition is needed for a system describing and categorizing martian sites of special scientific interest (special regions) and their level of contamination concern. The classification system shall be developed and employed in future planetary protection protocols, as well as in operational plans for later human missions to Mars.




# Forward Contamination (cont.)

3. Additional development and design attention is needed to characterize exploration, sampling, and base activities both to assure effective operation and provide the required level of planetary protection assurance
   - The processes associated with EVA egress/ingress must be characterized and optimized
   - An inventory of microbial populations carried aboard and potentially released by human-associated spacecraft and suits should be established and maintained in support of both planetary protection and crew-health objectives
   - An inventory of organic materials carried by, or potentially produced by, the mission should be established and maintained
   - Systems should be provided to allow controlled, aseptic, subsurface sampling operations.

# Forward Contamination (cont.)

4. Quantitative requirements to limit human-associated contamination in different zones shall be derived based on requirements for protection of special regions and applied to missions, with the following stipulations:
   - No quantitative bioburden requirements should be applied to landing systems or habitats, other than cleanroom (ISO 8 or better) assembly of Mars-contacting components
   - Spacecraft, landers, habitats, and rovers shall (to the maximum possible extent) filter material vented as gases, and shall not allow uncontained disposal of solids or fluids
   - Hardware elements involved with accessing special regions shall be subjected to a sterilizing process prior to use.

# Backward Contamination

1. All operations of a human mission to a new site on Mars shall include isolation of humans from directly contacting martian materials until initial testing (either precursor-mission or on-mission robotic testing) can provide a state-of-the-art verification of the landing site as a "zone of minimum biological risk" (provide for the informed consent of the crew).

2. Exploration, sampling, and base activities should be accomplished in a manner to limit inadvertant exposure to the subsurface or to otherwise-untested areas of Mars
   - A means for allowing controlled access to those areas shall be provided.

## Backward Contamination (cont.)

3. A site classification system and a biological plausibility map of the martian surface and subsurface, based on remote sensing data and on-mission testing, shall be employed during a mission to limit potential crew exposure to areas on Mars that might support martian life.

4. A quarantine capability for both the entire crew and for individual crewmembers shall be provided during and after the mission, in case potential contact with a martian life-form occurs
   – As part of normal crew health monitoring and in support of the assessment of possible quarantine measures, basic tests of the medical condition of the crew and their potential response to pathogens or adventitious microbes shall be defined, provided, and employed regularly on the mission.
   – A quarantine capability and appropriate medical testing shall be provided for the crew upon return to the Earth (Moon or Earth-orbit) and if necessary, implemented in conjunction with a health monitoring and stabilization program.

## Backward Contamination (cont.)

5. Samples returned by the crew from uncharacterized or otherwise-untested areas of Mars shall be considered as potentially hazardous, and shall not be released from containment unless they are subjected to a sterilizing process, or until a series of tests determines that they do not present a biohazard.

## Ops Group Report (cont.)

• What are the off-nominal events that could potential lead to contamination of Mars?

- Emergencies
  – Crash of cargo or human carrying vehicle, or a subset of spacecraft-carried material (jettison)
  – Fire in habitat suppressed by depressurization, or other factors resulting in breach of habitat integrity
  – Nuclear-power system thermal containment effects/breach
- Accidents
  – Tear or other failure in EVA system
  – Partial failure of ALS system or critical components
  – Waste containment/filtering breach
  – ISRU recovery contamination event
  – Nuclear excursion
  – Other power-system failure (battery leakage, fuel cell degradation/failure, tank explosion…)
  – Breach of pressurized rover
  – Failure to follow proper procedures (error due to fatigue, apathy or panic; medical incident/emergency; extremis)
- Amelioration involves site identification, documentation of incident, and possible remediation of localized contamination (biocidal foams?)

## Ops Group Report (cont.)

• What are the off-nominal events that could potential lead to contamination of the terrestrial biosphere?

- Emergencies
  – Crash of human carrying vehicle upon return to Earth
  – Exposure of crew to martian materials containing live organisms (crash on Mars, breach of containment of samples on Mars or enroute to Earth)
  – Emergency evacuation of Mars base to orbit (and Earth) in an unplanned fashion
- Accidents
  – Tear or other failure in EVA system
  – Breach of pressurized rover
  – ALS system contamination by martian materials (bioregenerative systems)
  – Return-vehicle breach/venting/jettisoning leading to possible uncontained return of Mars materials to Earth
  – ISRU contamination event
  – Failure to follow proper procedures (error due to fatigue, apathy or panic; medical incident/emergency; extremis)
- Amelioration involves documentation of incident, crew-quarters clean-up, quarantine of crew and medical monitoring and/or remediation)

## Ops Group Report (cont.)

• What are the R&D tasks required to cope with PP requirements?

1. Describe the potential impacts on the near-field martian environment of human support activities expected in the operation of a human-occupied martian base, e.g., breathing oxygen, food supply, waste management, etc., to determine the zone of contamination associated with a human landing, and the plausible limits of zones of no-contamination that can be preserved nearby.
2. Define the spatial dispersion of dust and human-associated contaminants on Mars by wind and other means.
3. Determine the survivability of Earth organisms and their component molecules in the ambient Mars environment, and in the conditions of the martian near-subsurface.
4. Examine future ALS designs and concepts with respect to planetary protection needs, especially with respect to organic and microbial contamination, to assess the potential effects of human activities in pressurized habitats and human-carrying rovers.

## Ops Group Report (cont.)

• What are the R&D tasks required (cont.)?

4. Examine future ALS designs and concepts with respect to planetary protection needs, especially with respect to organic and microbial contamination, to assess the potential effects of human activities in pressurized habitats and human-carrying rovers.

5. Examine future AEVA designs (thermal control, gas control, material leakage) with respect to planetary protection needs, especially with respect to organic and microbial contamination, to assess the potential effects of human activities on the martian surface away from pressurized habitats and human-carrying rovers.

6. Develop AEMC technology required for life detection and potential pathogen detection within the habitat or EVA system, with a focus on sensitivity and specificity of tests needed to identify potential microbes of unknown origin.

## Ops Group Report (cont.)

- What are the R&D tasks required (cont.)?

7. Develop field-deployable systems to monitor human-associated biological contamination released into the martian environment (autonomous/automatic, rapid, reusable, and/or low-consumable recharge).
8. Determine how to conduct human-associated robotic operations on Mars to be consistent with planetary protection concerns, both for those robotic resources deployed independently during precursor missions and for those deployed in conjunction with human landings.
9. Define and develop planetary protection protocols for use on human missions. Develop and test methodologies for implementation of those protocols using Earth-based simulations (laboratory and field), lunar experience, and an improving knowledge of the martian environment based on precursor missions. Define and implement a training plan for the crew and other personnel involved with the mission.

## Ops Group Report (cont.)

- What are the R&D tasks required (cont.)?

10 Provide robust and field-deployable systems to securely contain materials (wastes, propellants, etc.; for TBD durations) that may contaminate the martian environment.

11. Ensure that human factors research and design for human Mars missions will address biosafety considerations associated with planetary protection.

12 Provide for containment of Mars samples within human-occupied spaces, and for those returned to Earth.

13 Develop mitigation techniques to deal with human-associated contaminants released on Mars, and with contamination of human-occupied spaces by martian materials.